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ADVISORY GROUP FOR AEROSPACE RESEARCH & DEVELOPMENT

7 RUE ANCELLE, 92200 NEUILLY-SUR-SEINE, FRANCE

AGARD CONFERENCE PROCEEDINGS 579

Neurological Limitations of Aircraft Operations: Human Performance Implications

(les Limitations neurologiques des opérations aériennes: les Conséquences pour les performances des équipages)

Papers presented at the Aerospace Medical Panel Symposium held in Köln, Germany from 9-12 October 1995.

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North Atlantic Treaty Organization

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— Continuously stimulating advances in the aerospace sciences relevant to strengthening the common defence posture;

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Neurological Limitations of Aircraft Operations: Human Performance Implications

(AGARD CP-579)

Executive Summary

The Aerospace Medical Panel (AMP) of the Advisory Group for Aerospace Research and Development (AGARD) held a Symposium entitled "Neurological Limitations of Aircraft Operations: Human Performance Implications" at Deutsche Forschungsanstalt für Luft- und Raumfahrt, Cologne, Germany, 9-12 October 1995. The Symposium was held to address the factors which limit optimal functioning of the brain and other parts of the nervous system in air and support operations. Factors such as advances in technology, information overload, hazardous conditions, workload fatigue and sleepiness, head injury, drugs and inexperienced crew all affect decision making and place limitations on air and ground crew performance. Also considered were the practical challenges for enhancing brain performance for different operational environments.

The Symposium addressed a number of topics that will benefit the military. These benefits include:

- new directions for studying G-induced loss of consciousness resulting from the transition from negative G to positive G (push-pull effect) in high performance aircraft manoeuvers;
- consideration that candidates for pilot training demonstrating epileptic forms of brain waves not be selected as aircrew;
- confirmation that new aircrew protective garmentry employing pressure breathing allows both physical endurance and full mental performance to high G;
- indications that exposure to hypoxia may affect resistance to infection;
- possibility of designing "smart garmentry" for detecting onset of hypoxia in the cockpit;
- design of a computer administered system to detect subtle changes in mental function resulting from head injury;
- development of a new method to detect alcohol consumption in pilots;
- improved techniques for aircrew vision testing;
- new insights on the effects of workload stress and the ability to cope with stress;
- new drugs with no side effects for enhancing performance during sustained operations.

Because of the rapid developments in the brain sciences and in new technologies, the recommendation is made that AGARD/AMP hold further activities and other symposia in the next few years that further address the limitations and enhancements of the nervous system for different operational conditions.

les Limitations neurologiques des opérations aériennes: Les Conséquences pour les performances des équipages
(AGARD CP-579)

Synthèse

Le Panel de médecine aérospatiale (AMP) du Groupe Consultatif pour la Recherche et les Réalisations Aérospatiales (AGARD) a organisé un symposium sur "Les limitations neurologiques des opérations aériennes: les conséquences pour les performances des équipages" du 9 au 12 octobre 1995 au Deutsche Forschungsanstalt für Luft- und Raumfahrt, à Cologne en Allemagne. Le symposium a examiné les facteurs qui limitent le fonctionnement optimal du cerveau et d'autres éléments du système nerveux central lors des opérations aériennes et de soutien. Un ensemble de facteurs, tels que les progrès technologiques, la surcharge d'information, les conditions hazardeuses, la fatigue due à la charge de travail, la somnolence, les blessures crâniennes, les médicaments et l'inexpérience des équipages, ont une influence sur la prise de décision et imposent des limitations aux performances des équipages et du personnel à terre. Le symposium a considéré également les défis pratiques que représente l'accroissement des performances du cerveau dans différentes situations opérationnelles.

Le symposium a traité d'un certain nombre de sujets susceptibles d'être profitables aux militaires, parmi lesquels:

- de nouvelles orientations pour l'étude de la perte de connaissance liée aux accélérations (G-LOC) résultant de la transition entre les G négatifs et les G positifs (effet pousser-tirer) lors des manœuvres effectuées par des avions à hautes performances;
- des considérations sur l'élimination des équipages candidats à l'entraînement au pilotage qui présenteraient des ondes cérébrales de type épileptique;
- la confirmation que les nouveaux vêtements de protection des équipages incorporant la respiration sous pression autorisent à la fois l'endurance physique et le maintien complet des performances mentales normales même aux G+z élevés;
- des indications selon lesquelles l'exposition à l'hypoxie peut diminuer la résistance contre des infections;
- la possibilité de la création de "vêtements intelligents" pour la détection du début de l'hypoxie dans l'habitacle;
- la conception d'un système géré par ordinateur pour la détection de changements infimes dans les fonctions mentales suite aux blessures crâniennes;
- l'élaboration d'une nouvelle méthode pour la détection de la consommation d'alcool par les pilotes;
- les techniques améliorées pour le contrôle de l'acuité visuelle des équipages;
- de nouveaux aperçus sur les effets de la tension nerveuse induite par les charges de travail et la capacité d'assumer cette tension nerveuse;
- les nouveaux médicaments sans effets secondaires pour l'amélioration des performances lors des opérations de longue durée.

En raison de l'évolution rapide des sciences du cerveau et des nouvelles technologies, il est proposé que l'AGARD/AMP organise d'autres manifestations et d'autres symposia dans les années à venir pour examiner plus avant les limitations et les améliorations du système nerveux central dans différentes conditions opérationnelles.

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SESSION III: AGE, DISEASE AND TRAUMA

SESSION IV: NEUROSENSORY LIMITATIONS

SESSION V: WORKLOAD — EVALUATION AND MEASUREMENT

SPECIAL SESSION — ENHANCING NEUROLOGICAL PERFORMANCE IN AEROSPACE OPERATIONS: PRACTICAL CHALLENGES

† Not available at time of printing

Preface

NATO air operations in the future will have improved capabilities for mobility, flexibility, rapid augmentation and situation awareness. The rapid changes and sophisticated innovations taking place in technology imply that air warfare will become more knowledge intensive and, accordingly, more dependent on a well conditioned nervous system. Advancements in technology are also driving air and the concomitant support operations into the outer limits of human mental and physical endurance. There is also the requirement of doing more work with fewer resources. Critical to the success of future air operations will be an enhanced individual performance, better team work, improved intelligence, better training, more intellectual flexibility and resolve, the use of imaginative methods for overcoming obstacles, and better mental and physical fitness of air and ground crews. The purpose of this Symposium was to address some of the factors that impose limitations on the nervous system in meeting these goals, and to consider the practical challenges for enhancing neurological performance in such operational conditions as described above.

Topics addressed pertaining to neurological limitations and enhancements include:

- the Gz environment
- the hypoxia environment
- disease and trauma
- neurosensory limitations
- workload: evaluation and measurement
- stress effects
- workload: fatigue and sleepiness
- sustained operations
- enhancing neurological performance in:
  - heavy jet operations
  - rotary wing operations
  - air traffic control operations
  - ground and support operations

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TECHNICAL EVALUATION REPORT

by

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1. INTRODUCTION

The Aerospace Medical Panel (AMP) held a Symposium on "Neurological Limitations of Aircraft Operations: Human Performance Implications" at the research centre of the Deutsche Forschungsanstalt fur Luft- und Raumfahrt, Koeln, Germany, 9 - 12 October 1995. Thirty-seven papers and three invited Keynote Addresses were given by authors from nine NATO countries, Australia, The Czech Republic, and Sweden. There were 133 registrants at the Symposium.

2. THEME

NATO conceptualizes the use of multinational forces in the 1990s and beyond having improved capabilities for mobility, flexibility and rapid augmentation. A high level of situation awareness is envisioned, command and control will increase in importance, and the use of information processing technologies will be paramount for enhancing pilot performance. All of these conditions are dependent on the provision of optimal neurological performance by conscientious air and support crew. Accordingly, a full understanding is required of the functions and limitations of the brain in order to conduct effective performances under different operational conditions.

Effective aircrew performance in the modern cockpit requires intelligent decision-making and rapid reaction to threatening environments. The performance of the human brain in decision making can be enhanced by technological developments and training, and augmented by teamwork. However, factors such as head injury, sleep debt, degraded sensory information processing, inexperience, drugs, and behavioural deficits affect decision making and place neurological limitations on aircrew performance. This Symposium addressed the issues of neurological limitations and the enhancement of neurological performance in operational conditions from both the clinical and behavioural points of view.

3. PURPOSE AND SCOPE

Human performance limitations ultimately depend on the neurological limitations of the nervous system. Far too often, the brain's limitations and its performance enhancement capabilities have been overlooked, ignored or forgotten. The purpose of this Symposium was to bring together military and civilian specialists in clinical medicine and human performance to address some of the neurological issues that must be faced for effective aerospace operations into the next century.

The scope was broad, covering topics that addressed impairment of neurological function by the physical environment, sensory limitations, workload, disease and trauma. A panel discussion considered typical medical case studies and policy issues regarding neurological limitations in aircrew. A second panel discussion looked at the practical challenges of enhancing neurological performance in air and support operations. The symposium participants included military and civilian experts in aerospace medicine, neurology and neurophysiology, cognitive and experimental psychology, human factors, and bioengineering. Presentations were drawn from career pilots, flight surgeons, and investigators from defence research institutes, universities, and military and civilian medical centres and institutes.

4. SYMPOSIUM PROGRAM

The Symposium commenced with a Keynote Address that focused on the different strategies that must be considered in order for a pilot to effectively fly the modern high technology aircraft in threatening environments. This was followed by eight technical sessions, a special session and two panel discussions as follows, set out in chronological order:

a. Session I The Gz Environment: Neurological Implications and Enhancement of Performance
Chairmen: Dr J.P. Landolt, CA and
Mr J.L. Firth, UK

b. Session II The Hypoxia Environment: Neurological Implications and Assessment
Chairmen: Maj N.P.N. Ribero, PO and
Col Dr E. Roedig, GE

c. Panel Discussion: Neurological Limitations in Aircrew Environments: Clinical Case Studies and Policy Issues
Discussion Leaders: Mr J.L. Firth, UK and
Col Dr E. Roedig, GE

d. Session III Disease and Trauma: Neurological Implications and Assessment
Chairmen: Col Dr E. Roedig, GE and
Maj N.P.N. Ribero, PO

e. Session IV Neurosensory Limitations
Chairmen: Dr A. Leger, FR and
Dr J.P. Landolt, CA

f. Session V Workload: Evaluation and Measurement
Chairmen: Prof Dr W.J. Oosterveld, NE and
Cdr D.L. Dolgin, US

g. Session VI Stress Effects
Chairmen: Maj N.P.N. Ribero, PO and
Prof Dr W.J. Oosterveld, NE

h. Session VII Workload: Fatigue and Sleepiness
Chairmen: Mr J.L. Firth, UK and
Prof Dr W.J. Oosterveld, NE

i. Session VIII Sustained Operations and Strategies for Enhancement
Chairmen: Cdr D.L. Dolgin, US and
Dr A. Leger, FR

j. Special Session Enhancing Neurological Performance in Aerospace Operations: Practical Challenges
Chairmen: Cdr D.L. Dolgin, US and
Mr J.L. Firth, UK

k. Panel Discussion regarding Special Session
Discussion Leaders: Cdr D.L. Dolgin, US
and Mr J.L. Firth, UK

5. TECHNICAL EVALUATION

5.1 Keynote Address

In his Keynote Address on man in the modern military cockpit, Linder (Paper #K1) described three components considered essential for adjusting the high technology cockpit to the pilot's capabilities. They are:

- developing the right format for transferring the information optimally to the pilot,
- cognitively processing the information to enhance rational decision making, and
- optimally effectuating pilot decisions.

He spoke of the importance of human-decision making, fast reflexes, and good physical and mental health in flying the future agile aircraft. He considered that creativity and intuition will be just as important as technical knowledge in selecting future pilots.

5.2 The Gz Environment: Neurological Implications and Enhancement of Performance

Banks and Goodman (Paper #1) discussed in terms of the autonomic nervous system, the increased pilot susceptibility to G-induced loss of consciousness (G-LOC) when transitioning from -Gz to +Gz (push-pull effect). For -Gz exposures less than 5s, recovery of blood pressure matches the time of heart rate recovery. When exposure times are increased beyond 5s, blood pressure recovery is primarily mediated by the speed of vasoconstriction of the peripheral vascular beds. Banks and Goodman contended that designing adequate protection for pilots during the push-pull effect required further research on the response of the heart and vascular system to short-term parasympathetic and sympathetic influences. The recent fatal crash of a Canadian Forces F-18 aircraft due to the push-pull effect underscores the urgency in studying this issue.

Gray and Paul (#2) described the interesting experience of a pilot who was unable to maintain controlled flight in a simulator, following an episode of G-induced loss of consciousness during centrifuge training. In a real flight situation, this could have been a fatal accident. During the G-LOC incident on the centrifuge, the pilot experienced bilateral extremity jerking movements lasting 8s. Interestingly, on aircrew selection, his electroencephalograph (EEG) showed a 3 Hz slow wave activity, and he was classified as unacceptable. However, he was passed for pilot training based on a normal clinical neurologic review. Gray and Paul indicated that trained pilots showing such extreme motor activity during centrifuge training should be further screened for potential epileptiform EEG activity. Moreover, they argued strongly that candidates for pilot training with epileptiform EEG activity should not be accepted.

Results from centrifuge experiments conducted by Chelette and colleagues (#3) showed that the more advanced protective systems employing positive pressure breathing and full anti-G suit allow longer physical endurance to high G. Furthermore, based on the tests applied, these systems enable pilots to maintain full cognitive performance and mental workload throughout the extended exposure. Also, there were no neuropsychological decrements observed post exposure. Subjects in these studies repeatedly endured prolonged high-G exposures (some to +9Gz) to the point of subjective fatigue or painful discomfort

The thrust of Paper #4 by Firth was that there are multiple factors involved in dealing with the blood-brain barrier, and all of these must be designed into a G-exposure experiment.

There have been numerous studies that have accurately investigated the dynamics of head motion relative to the body during +Gz ejection. However, models generated from these studies do not consider the effects on the cervical spinal cord resulting from the sudden change in load caused by ejection from a high performance aircraft. Mazuchowski and colleagues (#5) used human cadavers, physical models and isolated tissue experiments to study the strain and strain rate produced in the head-neck region by the +Gz levels encountered in ejection. Results showed that neurological deficits will occur and pilot safety will be compromised during cockpit egress if the strain is >15% and the strain rate is >1/s. This implies that when the head centre of gravity is displaced, as is the case when wearing helmet mounted devices or ejecting with an improper body position, the potential for injury greatly increases. The authors further recommended that tests should be run to assess predicted strain differences in the male and female head-neck region under +Gz.

In a related study, using simple finite element analysis, Drew (#6) simulated the ejection of an aviator following an L5 hemilaminectomy. The model was subjected to the maximal G loading which occurs during ejection in a Martin-Baker seat. Although an increased stress to the L5 vertebra was indicated, at no vertebral location did the simulation exceed the maximal stress at which bone fracture occurs. This study demonstrated the usefulness of finite element analysis for determining ejection safety of an aviator having a diseased, surgically-intervened or otherwise abnormal spine.

5.3 <u>The Hypoxia Environment: Neurological Implications and Assessment</u>

Paper #7 by Neslein and K. Myhre addressed an important topic: the impairment of cellular phagocytic capacity in rats following repeated exposure to the stress of hypobaric hypoxia. Such a finding in the human may well mean that exposure to hypoxia adversely affects resistance to infection.

The belief has long been held that the accuracy of visual information processing is highly sensitive to hypoxia (MacFarland, 1969). This begs the question: Is the disruption by hypoxia specific to the visual system, and, if so, is it peripheral or central in origin? Fowler and Beach (#8), using kinaesthetic stimuli that bypass the visual centres, have demonstrated that central stages of information processing are unaffected by hypoxia, that slowing is specific to the peripheral visual system, and that this slowing may form a "bottleneck" on the nervous system as a whole to inhibit subsequent central information processing. The authors conjectured that application of this finding may permit pilots to accept a certain degree of stagnant hypoxia in return for an enlarged G envelope during

sustained high G manoeuvres.

Skinner and Gray (#9) described the development of an automated system that uses frequency domain shifts of EEG in neural networks to detect incipient cerebral hypoxia. The neural networks are trained to detect EEG spectral shifts from normal frequencies for different physiological states. The authors discussed the technical considerations and limitations in applying the concept as a miniaturized unit in "smart garmentry" for military applications. Possible civilian applications include monitoring brain ischemia in critical care situations.

5.4 Disease and Trauma: Neurological Implications and Assessment

Paper #10 which was to have discussed the implications of neurologic conditions on aircraft operations was not presented.

Paper #11 was to have discussed how deterioration of mental ability with age in conducting multiple task operations can be circumvented partially by employing appropriate training strategies which enhance learning, performance and transfer of skills in both young and older adults. However, the authors were unable to make this presentation.

The paper by Konrad and Dosel (#12) discussed head injuries in Czech Air Force pilots. Most head injuries occur from leisure time and other non-military activities. Return to flying is permitted for minor and, in part, moderate head injuries. This is conditional on having had regular checkups by a specialist in aviation medicine.

CogScreen-Aeromedical Edition (CogScreen-AE) is a computer administered and scored cognitive screening instrument designed to detect subtle changes in cognitive function. If left undetected, this could result in poor pilot judgement or slow reaction time in critical operational situations. Moore and Kay (#13) described its use in the evaluation of head injured military flight personnel. Results showed that, in comparison to conventional neuropsychological assessments, the CogScreen test hastened the return of head injured military aviators to flying duty.

Excessive body mass, when combined with factors such as cholesteremia, smoking, etc. represented a high risk condition for a cerebrovascular incident. Glaser (#14) studied the epidemiology of this risk in the German Air Force, and suggested a prospective study for an intervention strategy based on behaviour therapy to reduce obesity and cerebrovascular risk.

Alcohol abuse disqualifies many pilots from flight duty. Freund (#15) discussed the use of a new marker, Carbohydrate Deficient Transferrin (CDT), that the German Air Force Institute of Aviation Medicine introduced in 1994 as a diagnostic tool for determining alcohol consumption. CDT has demonstrated a 69% effectiveness in evaluating alcohol consumption in pilots, especially in those whose liver enzymes are elevated. From the same laboratory, Paper #16 was to have reported the results of psychometric tests given to pilots suspected of toxic brain damage. This paper, however, was not given.

5.5 Neurosensory Limitations

Visual-vestibular interactions during angular acceleration have been studied extensively. Correia in his Keynote Address (#K2) described results obtained from examining the infrequently studied case of visual-vestibular interaction during pure linear acceleration. Experiments conducted using a programmable elevator having a twelve-metre excursion demonstrated that there are fundamental differences in eye movements according to the nature of the visual-vestibular interaction during linear acceleration. Eye movements were enhanced or reduced in velocity according to the direction of visual target motion. These finding may have important consequences for pilots visually following a target during linear acceleration of the aircraft such as that which occurs during vertical take-off and landing, steep ascents and turbulence.

Rabin (#17) described the Small Letter Contrast Test (SLCT) as a powerful approach for extending the range of vision testing. (The SLCT has 14 lines of same-size, small letters and 10 letters per line. Lines vary in contrast in 0.1 log steps, and contiguous line letters differ in contrast by 0.01 log units. Normal room illumination is used for diagnosis.) The SLCT is

much more sensitive than standard visual tests for assessing and monitoring a number of clinical conditions. It could also be applied in assessing vision loss in pilot trainees and in aging pilots.

Burroughs and colleagues (#18) contended that formal visual field testing is necessary to properly evaluate an aviator with a condition such as optic nerve head drusen. They reviewed the pertinent aeromedical data of 18 evaluees diagnosed with optic nerve head drusen. Visual acuity, pupillary function, colour vision, depth perception and other measures of visual function were assessed. The results of ancillary tests such as those from imaging techniques and electrophysiological measurement of optic nerve function were also evaluated. The authors concluded that this defect can be compatible with the continuation of an aviator's career, provided acceptable levels of visual field function are maintained.

The most common etiological factors, including those from both Central Nervous System (CNS) and systemic causes, that contribute to transient vision loss in aircrew were considered in a second paper by Burroughs and colleagues (#19). The management and disposition of aircrew with these problems often represents a unique occupational predicament.

Paper #20 was to have demonstrated that a non-standard discrimination test, with phonetically unbalanced high frequency words in the presence of background noise, best correlates high-tone hearing loss with subjective complaints in aircrew. However, this paper was not presented.

Cavonius and colleagues (#21) considered the case of stimulus-response compatibility in a complex manual tracking task. Target tracking performance varied according to the complexity of the relationship between target trajectory and response tracking. These investigators concluded that stimulus-response compatibility needs to be considered in designing any manual control task requiring the operator to track a visual signal.

A paper by Diamantopoulas and Kechagiadakis (#22) discussed CNS impairment in perception, function and performance as imposed by vibration in flight. A companion paper (#23) was to have discussed motion sickness and disorientation as limitations in the perceptual orientation process. However, this paper was not presented.

The vestibulo-ocular reflex (VOR) assists stabilization of the retinal image by rotating the eyes to compensate for movements of the head. The standard VOR is characterized by its gain relating output (eye velocity) to input (head velocity) in one dimension. The Keynote Address by Fetter (#K3) discussesd a three-dimensional characterization of the gain in terms of the three component angular vectors of the eye and the head that make up the VOR in the real world. This generalization of the gain is a 3 x 3 matrix describing the dependence of all three components of eye velocity on all three components of head velocity. Experiments have shown this approach to be a better representation of vestibular function and disfunction than the standard method of obtaining the VOR. For example, tests on patients with the new method have demonstrated convincingly that vestibular neuritis may involve more than one division of the vestibular nerve.

5.6 Workload: Evaluation and Measurement

Pongratz and colleagues (#24) described the Flight Orientation Trainer (FOT) of the German Air Force Institute of Aviation Medicine in terms of its capacity for demonstrating the psychophysical load of flying personnel. The FOT provides a highly complex combination of specific indicators for assessing the degree of activation of the autonomic nervous system, CNS and humoral systems to multimodal stress demands. In particular, the FOT will be used as a training aid and research device in assessing pilot spatial disorientation.

Paper #25 was to have discussed the use of psychophysiological measures to assess cognitive activity when conducting complex tasks in simulation and flight environments. However, it was not presented.

Paper #26 was to have discussed current imaging techniques, such as positron emission tomography and functional magnetic resonance for assessing, evaluating and enhancing air crew performance. However, it was not presented.

Weinberg and colleagues (#27) described studies in which electrophysiological measures and neural net analysis were combined with behavioural measures to assess individual capabilities and limitations in processing complex multitask information. Two pilot studies were reported. In one, EEG activity was recorded during a simulated complex multitask exercise employed by Air Traffic Controllers. In this study, high gamma activity in the EEG was a better discriminator of performance than were evoked potentials. In the second study, both the EEG and magnetoencephalograph (MEG) were recorded in an environment where sleep deprived subjects were required to conduct a complex task. In this study, temporal lobe gamma activity in the MEG indexed performance better than did measures of event-related signals from the MEG or the EEG. The two studies taken together demonstrated the promise of using neural net analysis of the MEG and EEG as predictors of performance. This method has application in the training, assessment and identification of individuals for specific job requirements.

Investigating vigilance in detecting aircraft during NORAD surveillance operations was the thrust of a study conducted by Pigeau and colleagues (#28). Aircraft on display consoles employing a distinctive symbology were more easily detected than other targets. As might be expected, results showed that the midnight shift was particularly sensitive to decrements in vigilance. Also of interest is the observation that decrements in vigilance are not as strong in a real world task as those reported in laboratory studies. The authors suggest that, through the use of appropriate motivational factors, it may be possible to eliminate vigilance decrements entirely.

5.7 Stress Effects

The relationship between the immune system, CNS and the neuroendocrine system has been studied extensively, but has seldom been applied in aviation medicine. Medialdea Cruz and colleagues (#29) combined immunological techniques with conventional psychological questionnaire testing on Spanish Air Force pilots flying high performance aircraft to assess the effects of stressors on the immune system. They concluded that the method, although promising, requires further investigation for the detection and prevention of stressors in aircrew.

Glaser (#30) drew attention to the emotional stress such factors as divorce, health problems, etc. have on pilot performance. Pilots unable to cope with emotional stress are more likely to make errors leading to mishaps than those having no emotional problems. Strategies for improving the ability to cope with stress were discussed.

Fonne and G. Myhre (#31) addressed the issue of stress and coping factors during helicopter ambulance services. Stress during such missions include both physical and psychological factors. Previous studies have shown that emotional reactions to different stressful situations are reflected in neurohormonal activation. This study further demonstrated that there are individual differences in crewmember response relative to mission type, area of responsibility, and psychological coping strategies and the use of defence mechanisms. The authors indicated that further studies are required to determine the relationship between physiological reaction to stress and psychological coping styles.

5.8 Workload: Fatigue and Sleepiness

Porcu' and colleagues (#32) gave a good review of the current knowledge of fatigue and its effect on performance. They pointed out the differences between fatigue imposed by workload and that of operator effort, between physical exhaustion and psychological fatigue, and the distinctions between acute, cumulative and chronic fatigue. The relationship between fatigue and performance is also complicated by the interaction of variables such as motivation and the ability to cope with stress. These investigators recommended that the aeromedical community should identify early indicators of fatigue, establish useful diagnostic means for detecting and countering the different types of fatigue, and optimize the management of activities leading to fatigue.

Sleepiness is a well recognized neuropsychological limitation on effective aircrew operations. A study by Porcu' and colleagues (#33) of an acute night shift operation, reported that the relationship between sleepiness, alertness and performance is

complex. These authors concluded that in subjective and behavioural measures testing, each test plays a role in modifying the neuropsychological condition of the subject. Moreover, they indicated that a diverse set of subjective variables must be considered in order to obtain a true picture of this relationship.

The distinction between prospective (an expected judgement of time) and retrospective (unexpected temporal judgement) perception of elapsed time during an acute night shift was the subject of a study by Dell'Erba and colleagues (#34). The drug, temazepan or a placebo was taken in the afternoon prior to the night shift. Preliminary results indicated that both prospective and retrospective time estimations were not affected by night sessions and drug condition.

Mollard and colleagues (#35) have proposed a model to characterize and detect fatigue under laboratory conditions and in flight. The model takes into consideration such aspects as environmental conditions, circadian cycles (jet lag), work cycles, and work characteristics (type, duration and level of difficulty). These components are associated with interpersonal variations in fatigue. Long flights with their propensity for sleep deprivation, monotony and jet lag, and intense operations with their ability to rapidly induce mental fatigue are two particular scenarios that will be modelled.

5.9 Sustained Operations and Strategies for Enhancement

The effect of moderate sleep deprivation (twice for 27 hours) on vigilance and performance during a simulated sustained air mission was the basis of a study by Lagarde and colleagues (#36). Signs of disturbed vigilance and psychomotor performance were observed. Moreover, appropriately placed naps are adequate for recovery for limited sleep deprivation, but other countermeasures such as the use of drugs are required for recovery to repeated limited sleep deprivation.

The use of the psychostimulant drug, d-amphetamine to extend flight operations was the subject of two papers. Cornum and colleagues (#37) reported that the majority of F-15 pilots responding to a survey, used d-amphetamine on low task missions during Operation Desert Shield. Many pilots commented that it was necessary to take this drug during long duration, mostly night time, missions to prevent falling asleep. Caldwell and Crowley (#38) showed that d-amphetamine prevented flight performance decrements attributable to sleep loss in males and females in controlled laboratory studies in a UH-60 helicopter simulator. Sleep recovery was less restful under the drug, but, practically speaking, this is minimal given the pressure to sleep when sleep deprived. Caldwell and Crowley recommended administrating d-amphetamine prophylactically to prevent deterioration associated with sleep loss in sustained operations.

Pigeau (#39) compared the effects of modafinil and d-amphetamine on cognitive performance and core temperature during sixty-four hours of sustained work. Modafinil is an alerting substance that is considered safer than d-amphetamine with fewer side effects. Subjective estimates of mood and objective measures of mental performance were superior with both modafinil and amphetamine compared to that of a placebo. Pigeau suggested that modafinil may be an attractive alternative to d-amphetamine for maintaining or recovering performance because of its comparable effectiveness with fewer side effects.

The pineal hormone signals the nocturnal phase of the human circadian cycle. Experiments have shown that melatonin administered orally prior to undergoing diurnal sleep extended average sleep times compared to that when taking a placebo. Furthermore, no side effects from melatonin have been reported. French (#40) studied melatonin's effect on C-5 flight crew during a staged eastward deployment to Europe lasting 6 - 12 hours. He noted that subjects' circadian rhythms were comfortably adjusted within 24 hours of arrival.

5.10 Enhancing Neurological Performance in Aerospace Operations: Practical Challenges

Papers in this special session were solicited to address the neurological implications of enhancing performance in:

- heavy jet operations,
- rotary wing operations,
- air traffic control operations, and

• ground and support operations.

Fry (#S1) focussed on the major issue of concern in heavy jet operations: a commitment to safety through a systems approach. This takes into account new technology, training, human factors, support systems and external factors. Fry acknowledges that "...some impressive engineering solutions ... have resulted in only scant consideration of the 'man-machine' interface." Human factors training is now mandatory for initial and recurrent training of flight crew of airlines operating internationally.

Flying helicopter missions requires more cognitive and sensorimotor demands than is the case with fixed wing operations. There are the stresses imposed by flying nap-of-the-earth while encumbered by night vision devices, the oppressive thermal conditions that may persist throughout the mission, and now the attendant hazards of sleep deprivation and circadian desynchronization resulting from the rapid deployment of helicopter crews to distant lands. There are also the attentional demands of mastering a complex computer system while simultaneously flying. Crowley (#S2) suggested that improvements in the quality of information presented to aircrew would reduce workload and the number of accidents due to disorientation. Improved night vision systems, better instrumentation and three-dimensional audio systems are some of the ways this could be achieved. Also, neurological performance under stress could be maintained by developing a customized crew endurance plan that addressed work/rest cycles and operational medications for different combat environments.

Performance in air traffic control operations is dependent on the internal working environment, weather conditions, traffic workload and the individual characteristics of the air traffic controller. Della Rocco and colleagues (#S3) focussed on the effect of fatigue induced by rapidly-rotating shift work on controller performance in both the laboratory and the operational work environment. Coping strategies, including management of sleep cycles, circadian rhythms and work schedules, and modifications to the environment were some of the countermeasures that could be implemented to enhance performance.

Barker and Hain (#S4) considered the challenges facing naval aviation leaders in improving performance in flight deck personnel during ground and support operations aboard an aircraft carrier. The environment on an aircraft carrier during duty is intense, prolonged and potentially dangerous. Conditions such as high workload, sustained operations, heat and cold, wind and rain, noise and vibration, neurosensory deficiencies, and emotional and interpersonal problems are some of the major factors that impose neurological limitations on flight deck personnel. The challenge is to find better ways to screen, evaluate, educate and train flight deck personnel, and devise better ways to handle morale issues to enhance flight deck performance. Additionally, current research findings must be more quickly and effectively applied to enhance performance (e.g., the use of performance enhancing drugs).

6. CONCLUSIONS AND RECOMMENDATIONS

In 1990, the United States designated the following ten years as the decade of the brain. The focus was to be on prevention, research, treatment and rehabilitation of brain related diseases and disorders. Following the urging of the World Health Organization in 1991 that all governments should do the same, many countries passed a similar initiative including the member states of the European Community and Canada. It is timely and appropriate, therefore, that this Panel in 1995 should capitalize on the relevant advances made by researchers in these countries and apply the knowledge to a better understanding of the limitations of, and the practical challenges for, enhancing nervous system function in the aerospace environment.

This Symposium has drawn attention to some very interesting and important research developments in the neurosciences that the aviation community is exploiting to enhance performance. However, the field of neuroscience is so large that it is not possible to cover every facet that impacts on the issue in a single symposium. For example, Banks and Goodman spoke of the role played by the autonomic nervous system on G-LOC when transitioning within the Gz environment. However, no one has explored G-LOC and recovery from G-LOC at the cellular brain level in the search for

protective measures against this deleterious phenomenon. Similarly, Correia described the implications of following a target visually during linear accelerations, and he spoke of the great strides made in our understanding of the effects of angular acceleration on visual-vestibular interactions. Again, no one has considered the mechanisms and protective measures required to counter the disorienting neurosensory mismatches that will be imposed by the combinatorial translational accelerations and angular motions encountered in enhanced manoeuvreability aircraft. It is an issue that needs to be addressed rigorously before consideration is given to further develop these aircraft for combat roles.

Even those papers that were presented on the application of new advances to issues of human performance and safety in air operations are just the beginning of research in this area. For example, although the important topic of impact head injury was addressed in this Symposium, new knowledge of injury mechanisms and trauma treatment including drug intervention, new advances in protective countermeasures, etc. were not discussed. There are sufficient new advances on impact head injury alone to hold a separate symposium. This also applies for other topics in this Symposium.

The excellent presentations and the ensuing panel discussion at the Special Session have shown that there are many research challenges for enhancing human performance in air and support operations. Regardless of the mission, however, all of the operations discussed in the Special Session are faced with the same problems of adaptation to new technology, information overload, hazardous conditions, workload fatigue and the requirement for teamwork and training. Most importantly, these papers identified, or inferred , the areas that need to be resolved if enhancing neurological performance in the aviation environment is to become a reality. The challenge is there for the AGARD aeromedical community to resolve these issues.

This is the second symposium that the AMP has held which addressed the human performance implications of neurological function. In 1987, a very successful meeting was held in Tronheim, Norway on the electric and magnetic activity of the CNS and its implications to aerospace operations (Conference Proceedings AGARD-CP-432). It would be prudent for the AMP to monitor progress in the neurosciences and hold further activities and a third symposium within the next few years to remain abreast of developments in this burgeoning discipline.

7. ACKNOWLEDGEMENTS

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Man in Modern Military Cockpit. -Strategies in the Pilot's Mind

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Introduction

The Man and the Machine. Very few relations are so complex, filled with drama and yet by far not fully scientifically documented. While technicians always have had high requirements for estimations, numbers, validity and so on, their interest for human performance have not always been that outspoken.

This might review an opinion during this century of the Machines saying that these technical innovations have their limits but Man can and will adjust to the machine and furthermore in addition he might also suffer physical and psychological stress, hunger, thirst, hot and cold environment and still be able to make good rational decisions. Decisions which sometimes could be made after carefully choosing the best of several alternatives but they could also be an act of reflexes in a fraction of a second.

Our goal must therefore be to expand the knowledge of Man in his relationship to the machine, the aircraft. Even if the technology can reach faster, stronger, better performance, we must remember that the ability of man to safely and effectively under time pressure, perform an increasing number and more difficult tasks is clearly restricted.
Physiologically and psychologically we are still almost the same human beings as our ancestors living in those caves.

Aviation in a historical perspective

The pilot of the early days was supposed to be a gentleman and a sportsman. The enemy in the dogfight should be given a fair chance and might also have had the opportunity to take the first shot!
The instruments in the cockpit were very simple and not that trustworthy. The pilot had to trust his own senses. A special "sense" for flying was important. The pilot should be healthy, physically and mentally, but testing and selection methods were simple.

Air Forces have since then undergone a tremendous development. Sofisticated technique and complex systems. The 3-dimensional war is today transferring into a 4-dimensional where time and restrictions of time are becoming some of the most important features.

The pilot of today must like his predecessors be able to master his platform and the weapon system. But technical and tactical improvement of todays aircraft systems put focus on the pilot as the limiting factor. So from now on we have to adjust the high-tech systems to fit the pilots ability and capacity. We will not have an optimized integrated system without that.

Remember that high-tech aircraft systems mainly have been developed by technicians with ambitions to improve the possibilities of the pilot in the cockpit. The knowledge about human limitations has not always been considered and furthermore pilots themselves have often been fascinated by technical improvements while having a somewhat weak insight of their own limitations.

Human factors in mishap statistics tell us that we have not been able to primarily adjust technology to man. Instead we must admit that the technological improvements have been linked to an unrealistic belief that human capacity can optimally handle all theoretical possibilities of a new high-tech aircraft system.

Scenario of a future war

Information on the enemy's disposition will be most important. New precision weaponry, sofisticated sensors, modern communication with networking capacity and high-tech aircraft systems with e.g. stealth-technique, will create a very dynamic battlefield. Targets will be very agile and mobile, time for identification and decision to fire will be very short. Weather will not be much of a hindrance. Engagement between aircraft will at least start as a BVR-fight (beyond visual range).

In this arena some things can be automated but human decision-making will still be most important and important in the respect that even operative and strategic decisions might be taken by individual pilots. Add to this that every single aircraft, every one representing a substantial economical value in the decreasing number of the fleet also will have a substantial military power.

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This indicates that there will be fewer pilots, everyone more valuable and their internal resources must be the same as their generals. Borders between tactical, operative and strategic issues will be erased. But still fast reflexes, good physics and sound mental health will be needed. The advantage of a pilot compared to a robot will be the human ability to choose alternative solutions. Intellectual capacity together with an open mind and a solid base of operative and tactical knowledge will also be cornerstones.
This equation might be very difficult to satisfy, but maybe the backbone of pilots in future air forces will consist of 40-50 years old, healthy pilots with a great body of experience.

One interesting question which deserves to be brought up when talking of pilot-profiles is whether creativity and intuition will have to be just as important as technical knowledge. Some air forces claim that there are great similarities between the artist, the creative human and the military pilot.

The Swedish JAS Gripen project

The JAS 39 Gripen now under implementation in the Swedish Air Force is just not only a military fighter aircraft but it is meant to be a complete weapon system. It consists of a multirole aircraft, its radar and other electro-optical sensors, other Gripens, a fighter control system and our specialized dispersed road-base system. Every component tied together with a real-time datalink system.
In addition there are dôme-simulators, tactical simulators and equipment for planning and evaluating missions.
The aircraft itself has a digital fly-by-wire system, a glass cockpit with many pilot-friendly features.

The pilot will be integrated into the system via information which will be presented to the pilot, he has to make good decisions while under different kinds of external and internal pressure and then execute his decisions via mainly throttle and stick "hands on" (HOTAS). He will thereby give his input to an integrated system which operates many subsystems automatically in a so called "inner-loop".

A very important question is how much authority should the pilot be able to give to the "inner-loop". I think that this authority must depend on which type of subsystem and during what circumstances the pilot is maneuvering the subsystem. In some cases when the pilot is put under extreme pressure his stick-movements may have to be filtered, otherwise his input may result in a non-recoverable situation.

Man in the Flying System

1. The first link of the chain consider the transfer of information to the pilot via different medias of presentation. How do we get the right format for optimal perception. This is crucial for best situational awareness.

To me the visual input is by far the most important in flying. Since flying is not a "natural gift" for mankind you need to use the most developed of your 5 senses. Feeling and vestibular apparatus (acceleration) can easily be tricked.
I would rank our senses in relation to flying in the following order: Sight, Feeling, Hearing. Smell, Taste. And in addition I am greatly in favor of input stimuli which are very natural (analog) and easy understood and thereby often similar to what the pilot experiences in normal life.

To use such stimuli mean e.g. a very wide HUD (head up display) to get a good stimulation of your peripheral vision for "instant" spatial orientation cues. This will be even better when HMD:s (helmet mounted devices) will be introduced.
To improve the information for the visuals there is intense research ongoing considering colors and different types of symbols, 3-D presentation and so on.

Hearing is also an important information channel. Besides normal communication with air-controllers there are certain analog signals giving different kinds of warnings. Ongoing research indicates that 3-D sound gives faster detection of a hostile target.

2. The second link deals with processing the information and how to get the rational for a good decision. This process, the cognitive process, is dependent on factors like the state of arousal, basic needs, intelligence including intuition and creativity, knowledge and not least experience. These above mentioned factors will then also put our focus on selection issues, training, life in the squadron and how leadership is implemented.

Considering a pilot in a fast jet, it is necessary to make a clear distinction between such a situation for a human being and that of a deep discussion between two or more people.
In the first case you cannot relax ever and disregard incoming stimuli some of which could be real life-threatening. In the latter case on the contrary you might be able to turn "inside yourself" to get hold of the best and most innovative arguments thereby even disregarding a beautiful woman walking across your view .

Flying therefore seems to be much more of a fast working memory process, where fast recognition, reflexes and easy retrievable knowledge and experience will lead to fast and adequate decisions.
It must therefore be of great importance that the pilot sometimes can substitute high cognitive analysis with intuition and creativity for best choice. So with actual

knowledge and experience paired with an open mind and an openness for new unproved hypothesis I do think such pilots will prove to be "the right stuff".
Having this in mind incoming stimuli have to be analog if possible, i.e. not too many words, letters and numbers.

Returning for a moment to a threatening situation. Incoming stimuli will turn optimal arousal into stress and thereby making higher cognitive analysis and reasoning impossible. No matter how stress- resistant you are as a pilot. Every sound pilot has his limit.

3. The last link in this chain will then focus on how does the pilot effectuate his decisions. It seems unlogical to use a true afferent sense-organ and its linked motor apparatus, for too many "motor tasks". That is because we would then have to put too much "brain-power" on feed-back control mechanisms if we use e.g. the eyes and voice to effectuate decisions instead of ordinary hand and finger movements. A finger-push on a button gives a very definite feedback and you can "mentally leave" that part of a given task.
Nevertheless short voice commands for shifting radio frequencies and using "gaze" as aiming device for a target-tracker could be very rational.

We all live in the midst of the future where technology, industry and military seem to hesitate somewhat. My feeling is that they all hesitate due to the danger it could create to rush on and implement all the most modern technology. We have to consider that a human being still has to be brought onboard the machine to make the system, of course, more unpredictable but also probably safer in the sense that man and only man can avoid war in contrast to preprogrammed machines and robots.

NEUROLOGICAL INFLUENCE IN PUSH-PULL EFFECT

by

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INTRODUCTION

During straight and level flight, aircraft occupants are exposed to the normal acceleration force of gravity, that is +1 Gz. Evolutionary development of homeostatic control of blood pressure (BP) via neurological and cardiovascular mechanisms occurred under the continuing influence of +1 Gz during walking or sitting. Thus, humans have not yet evolved mechanisms to compensate for significant excursions from +1 Gz. Aircraft occupants are frequently exposed to short duration accelerations other than +1 Gz (12). Air turbulence, for example, exposes occupants to short (up to 0.5s) exposures to ± Gz. Coordinated banked turns in jet aircraft expose occupants to sustained increases in +Gz. Nose-down, or 'bunt' maneuvers expose occupants to relative -Gz (that is, Gz that is less than +1 Gz).

Understanding of the effects of exposures to variations in Gz is incomplete. Because sustained increases in +Gz occur commonly in flight and can be studied in laboratories with the use of human centrifuges, much work has been accomplished. However, research conducted on human centrifuges commonly suffers from the bias of a starting baseline of +1.4 Gz, a condition that seldom exists in actual flight (3). Much less is known of the effects of increased +Gz when the starting condition is less than +1.4 Gz.

The few studies that report on G-tolerance when +Gz baseline varies are preliminary, but have demonstrated that tolerance to +Gz decreases more when preceding Gz is relatively more negative (4, 6, 27, 37). This effect, termed the "push-pull effect", increases with increased time of exposure to preceding relative -Gz (5, 27, 37). In-flight studies have shown that a proper anti-g straining maneuver (AGSM) and/or g-suit inflation only partially counters push-pull effect (37).

The recent fatal crash of a Canadian Forces CF-18 due to push-pull effect has highlighted the inadequacies of current protection strategies. Prevention of similar accidents requires completing our understanding of acceleration physiology. As a rationale for future research efforts aimed at achieving this understanding, this paper discusses the possible neuro-cardiovascular processes involved in push-pull effect.

NEUROLOGICAL MECHANISMS OF BP CONTROL AT +1 Gz

During straight and level +1 Gz flight, short term BP control occurs via the autonomic nervous system. The parasympathetic system is normally dominant in rest at +1 Gz, blunting sympathetically-mediated increases in BP sensed at the upper thoracic and carotid baroreceptors.

The baroreceptors are stretch receptors that sense change, and rate of change of transmural pressure (8, 26, 30, 32). A change in transmural pressure sensed at the baroreceptor results in a transmitted signal centrally to the medulla (1, 26, 30, 31). After central processing, parasympathetic efferent response occurs via the vagus nerve to the heart, and parasympathetic-mediated outflow to the peripheral circulatory system. Vagal parasympathetic influence results in rapid cardio-deceleration, and decreased cardiac contractility. Parasympathetic inhibition of efferent sympathetic nervous system-mediated vasoconstriction results in relaxation of vascular smooth muscle and vasodilation. BP is therefore reduced as a result of decreased cardiac output (secondary to reduced heart rate (HR), cardiac

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filling, and cardiac contractility), as well as increased vascular conductance due to circulatory vasodilation.

Conversely, a decreased transmural pressure presented to the upper thoracic and carotid baroreceptors is similarly interpreted centrally as a reduction in BP, and increased sympathetic efferent activity results. Increased sympathetic influence to the myocardium occurs via the glossopharyngeal nerve and results in cardio-acceleration, but at a rate slower than parasympathetically influenced cardio-deceleration (4, 13) and, presumably, increased cardiac contractility. Sympathetic effector activity to vascular smooth muscle via efferent sympathetic nerves results in peripheral resistance vessel vasoconstriction (skeletal muscles and splanchnic beds). These reflexes consequently restore BP as a result of increased cardiac output (CO) due to a faster beating, greater contractile heart and increased peripheral resistance due to arteriolar vasoconstriction.

The net effect is that in health, BP is tightly regulated, such that mean BP varies little, even during reasonably rapid postural changes from supine to +1 Gz upright positions.

BLOOD PRESSURE REGULATION UNDER INCREASED +Gz

The role of the sympathetic nervous system in maintaining BP during increased +Gz is understood (28), and matches the model described above. Under increased +Gz, HR compensatory response is complete within 5-12 s (16) As BP decreases in the upper body under increased +Gz, sympathetic efferent mechanisms are activated by arterial and cardiopulmonary baroreceptors. Depending upon the extent and rate of +Gz onset, the reduction in the relative hydrostatic column between heart and head may be too great for these BP compensatory mechanisms to become effective. In this case, head (eye) level hypotension leads to "grey-out", "black-out", or G-induced loss of consciousness (G-LOC) (11, 28, 40, 44).

When cerebral ischemia develops under increased +Gz, intracellular substrates allow continued brain tissue function for 5-7 s before symptoms occur (40, 41, 42, 43). This period of substrate latency is extremely important since it defines the time available for compensatory mechanisms to be effective in preventing G-LOC. Also, protective countermeasures (e.g., G-suit inflation, AGSM) must be effective within this time period.

EVALUATING THE PHYSIOLOGICAL MECHANISMS IN PUSH-PULL EFFECT

Bradycardia during relative -Gz is caused by parasympathetic influence (4, 6, 14). This influence occurs because of increased transmural pressure on the upper thoracic and carotid baroreceptors due to the increased weight of the inverted hydrostatic column. As described above, other anticipated effects would be decreased cardiac contractility and peripheral vasodilatation. Tolerance to subsequent +Gz then depends on the ability of the body to reverse these conditions within the 5-7 s period of brain substrate latency. When evaluating transition from -Gz to +Gz, therefore, the following mechanisms must be effected rapidly in order to maintain cerebral perfusion:

1. bradycardia (-Gz) reverting to tachycardia (+Gz)

2. low cardiac contractility (-Gz) reverting to high contractility (+Gz)

3. excess atrial/ventricular preload (-Gz) reverting to normal or reduced atrial/ventricular preload (+Gz)

4. peripheral vascular vasodilation (-Gz) reverting to vasoconstriction (+Gz)

1. Bradycardia (-Gz) reverting to tachycardia (+Gz). Bradycardia occurs within 2-4 s under the influence of -Gz, although some recovery in HR may occur with sustained exposures to -Gz (9, 17, 24). Tachycardia during +Gz becomes established at a slower rate, taking 6-8 s (4). This point is illustrated in Figure 1, which is an example of HR recordings taken from two Canadian Forces pilots during flight. Since the 6-8 s recovery time is greater than the 5-7 s of substrate brain latency, it is likely that this mechanism contributes to symptoms experienced during push-pull effect.

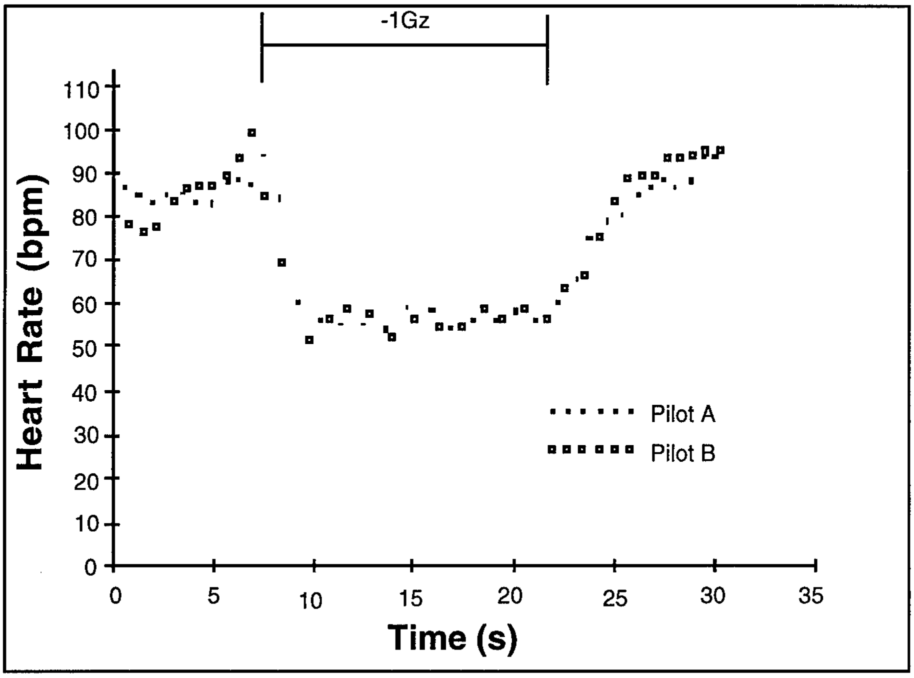

Figure 1. Heart rate recordings from two pilots. Rapid drop in HR occurs immediately on transition to -1 Gz from +1 Gz. Note stable bradycardia plateau, then slower recovery when flight is resumed at +1 Gz.

2. Low cardiac contractility (-Gz) reverting to high contractility (+Gz). Extrapolation of cardiac contractility changes under autonomic nervous system influence during ±Gz is based upon studies conducted at +1 Gz. Understanding the place of this mechanism in BP recovery from -Gz to +Gz transitions is complicated by the limited understanding of myocardial energetics during -Gz (33) and +Gz (29), as well as the opposite and competing influences of cardiac filling. During -Gz, high parasympathetic tone attempts to decrease cardiac contractility, however, this is superimposed upon increased atrial filling due to increased venous return. Conversely, during subsequent +Gz, contractility will increase under sympathetic influence, but the time course is difficult to predict and is currently unknown. Thus, the role of cardiac contractility in push-pull effect is currently undefined.

3. Excess cardiac diastolic filling (-Gz) reverting to normal filling (+Gz)
The diastolic filling of the atria and ventricles (by increases in venous return) is known to greatly influence the heart's output (via Frank Starling Mechanism) (20). During -Gz exposure, right atrial filling will transiently increase markedly. In one +1 Gz study with high levels of positive pressure breathing, over-pressurization of a full-coverage G-suit was shown to translocate blood into the thorax, increase end-diastolic filling rate, and slow heart rate below resting conditions (19). It is probable that cardiac mechanoreceptors (7, 23) might also interact with cardiovascular centres (in concert with arterial baroreceptors) to slow heart rate in excessive venous return conditions. However, during subsequent +Gz, the ventricles are unloaded, and the normal BP rise is dependent upon a rising CO secondary to adequate venous return and diastolic filling.

4. Peripheral vasodilation (-Gz) reverting to vasoconstriction (+Gz). Total peripheral resistance (TPR) is normally derived as BP/CO and depends on measurements made over a steady-state period of time in excess of the 5-7 s period of brain substrate latency. Derived TPR in evaluation of push-pull effect is therefore not valid, and modifications of this classical expression must be developed for acceleration

physiology. Very little work has been done to directly measure the changes in either the venous or arterial vascular systems in response to parasympathetic or sympathetic stimuli. Recent work has, however, suggested that both peripheral arterial and capacitance vessels participate in ±Gz responses (38). The vascular walls are composed of smooth muscle, a typically slow responding end-organ (30, 31, 32). Increased sympathetic tone causes contraction of smooth muscle in the vessel wall; parasympathetic influence blocks sympathetic tone and allows relaxation of the vessel wall, and vasodilation. Of interest in consideration of push-pull effect is the time-response of this smooth muscle. Complicating features relate to locally-mediated vasodilation in skeletal muscle beds caused by prior AGSM, which could also induce further peripheral vasodilation during subsequent -Gz.

Clues to the time-response of the vascular bed can be found in several reports. Wallin and Eckberg (39) noted vasodilation periods of 9-15s during neck suction experiments that simulated -Gz type impulses. Gauer and Henry (18) demonstrated during -Gz that BP typically changed immediately, according to the expected hydrostatic column inversion. A further reduction which occurred secondarily was interpreted as continued peripheral vasodilation under -Gz influence. Peterson and colleagues (36) reported that peripheral resistance did not begin to increase until 5.8 s after exposure to +Gz, in dogs. Maximum vasoconstriction was not achieved until 20.4 s following onset on +Gz. Guyton (21) reported that the full pressor response in dogs took 13 s, with 7-10 s for the initial response and up to 15-20 s for full expression. Brown and colleagues (10) demonstrated that in humans exposed to lower body negative pressure (simulation of +Gz), total peripheral resistance was maximum after 14 s.

Additional clues to the time-response of the vascular bed may be found in the wave-length of vasomotor waves, otherwise known as Mayer waves or Trobe-Herring-Mayer (THM) waves. These waves are embedded within normal respiratory fluctuations in HR and BP tracings. Guyton and others (22, 35) described these in hemorrhaged dogs, and felt that they represented a measure of the speed of response of the baroreceptors. Similar waves have recently been identified in human subjects exposed to high +Gz in the DCIEM centrifuge (Buick, F. personal communication). Techniques such as spectral analysis have further refined our understanding of the period of these waves, and indicate an average of about 10 s for humans (2, 15, 34). Much work needs to be done to further define the meaning of these waves. They may represent a measure of the time-response of the smooth muscle of the vascular bed to perterbations in BP, and/or alternating competition between the high and low-pressure (cardiopulmonary) baroreceptors.

Of particular significance in consideration of push-pull effect are the recent findings of Doe and colleagues (13). Using the dog model, they have demonstrated that parasympathetically mediated vasodilation is a more rapid process than sympathetically mediated vasoconstriction. This finding suggests a time response that parallels HR response during -Gz. If true in the human, this difference in parasympathetic-sympathetic response times may further explain the occurrence of push-pull effect.

If relaxation-contraction of resistance vessel walls is a significant mechanism in push-pull effect, it follows that the effect will be lessened if any portion of the arterial tree becomes more rigid and therefore a less responsive end-organ to contraction-relaxation inputs. Since vessel wall rigidity increases with normal aging, due primarily to atherosclerosis (25), it also follows that older subjects might be less susceptible to push-pull acceleration stresses. During pilot laboratory studies on push-pull effect, two healthy males aged 48 and 58 yrs showed minimal or no susceptibility to push-pull effect (Banks, R.D. unpublished data). While not constituting scientific proof, these observations are consistent with the notion that the compliance and reactivity of the vascular bed plays an important role in the etiology of push-pull effect.

	+1Gz control	2s - 2 Gz	5s - 2 Gz	10s - 2 Gz	15s - 2 Gz	Total
Light loss	0	1	2	6	4	13
No light loss	12	5	4	6	2	29
Total	12	6	6	12	6	42

Table I. Subjects' reported incidents of visual light loss during 15-s exposure to +2.25 Gz, following preceding flight at +1 Gz (normal flight), and -2 G for 2-, 5-, 10-, and 15 seconds.

CURRENT STUDIES

In consideration of the relative importance of each of these mechanisms, Figure 2 is presented. Figure 2 depicts the averaged systolic blood pressure (BPs) of groups of subjects exposed to +2.25 Gz for 15 s following exposure to +1 Gz, and exposures to -2 Gz for 2-, 5-, 10-, and 15 s (taken from (5)). The difference in each of these BP plots from the plots preceded by +1 Gz (baseline) can be considered a quantification of loss of +Gz tolerance. Table I (taken from (5) and (6)) consolidates the reports of visual light loss by subjects during these experimental conditions, and shows that subjective assessment of light loss correlated well with quantitative estimates of +Gz tolerance loss shown at Figure 2.

Evident from Figure 2 is the observation that the 2- and 5 s exposures to -2 Gz result in very similar plots. Also evident is the fact that BP recovery is complete within 6-8 s of exposure. This recovery period matches the recovery time period of heart rate following -Gz (4). For purposes of comparison, Figure 3 depicts the 2 and 5 s exposures to -2 Gz with superimposed heart rate recovery data recovered from pilots exposed to -1 Gz in flight.

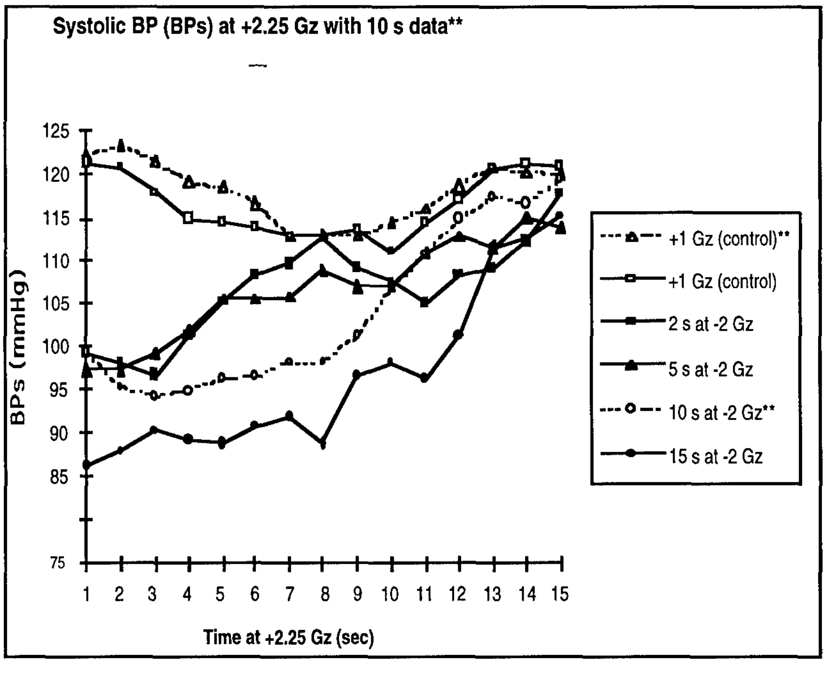

Figure 2. Systolic BP of subjects taken from two studies (5,6). BP was recorded while subjects experienced +2.25 Gz following exposure to -2 Gz for various periods of time.

Further inspection of Figure 2 indicates that 10- and 15 s exposures to -2 Gz result in greater loss of Gz tolerance, and slower recovery. By implication, a mechanism other than HR rate recovery must be responsible for continued BP recovery beyond HR recovery.

DISCUSSION

The BP recovery time at +Gz following short duration (less than 5 s) exposures to -Gz matches the time recovery period for HR. As the time of exposure to -Gz increases beyond 5 s, BP recovery time increases beyond the time for full HR recovery. This increase becomes greater with more time at -Gz. Figure 4 shows the 10 and 15 s BP recovery plots with HR recovery data superimposed. In this case, the longer duration spent at -Gz (10 and 15 s) preceding immediate exposure to +2.25 Gz results in a more prolonged recovery of BP than for the 2 and 5s -Gz exposures.

These observations illustrate that HR increase may be the predominant mechanism of BP recovery for short exposures to -Gz (less than 5 s). When -Gz time exposures exceed 5 s, HR recovery alone is insufficient to effect full BP recovery. This suggests that vascular bed reactivity plays an increasingly important role in BP recovery for longer exposures to -Gz. Using clues to the speed of reactivity of the vascular bed, we might be able to assume a period of either full vasodilation, or full vasoconstriction of 7-15 s in humans, noting in the process that vasodilation may be the faster of the two processes (13).

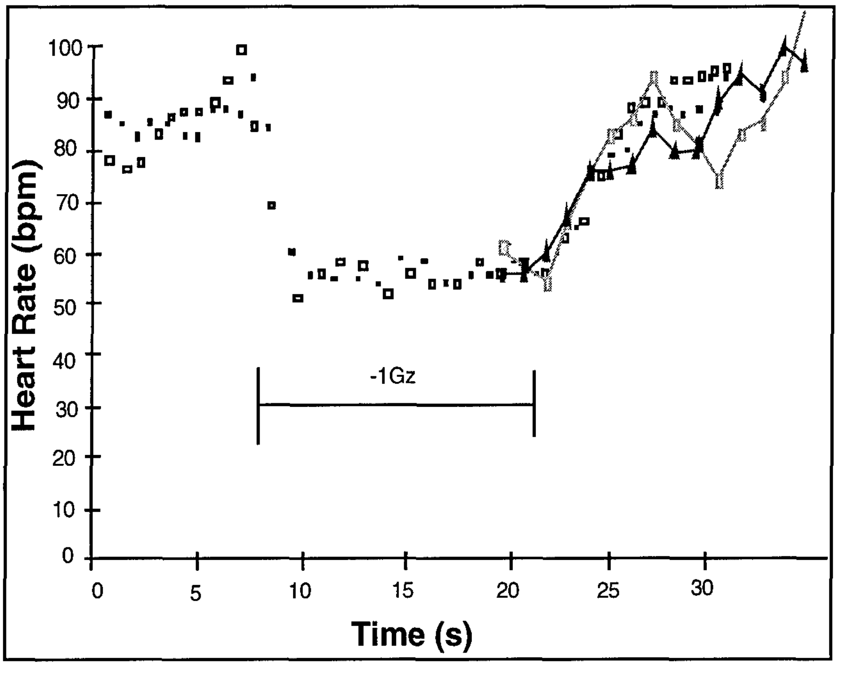

Figure 3. Recovery of blood pressure at +1 Gz after exposure to -Gz. Closed and open boxes are in-flight heart rate data for pilots A and B(from figure 1), respectively during maneuvers from +1 Gz, to -1 Gz, and to +1 Gz; heavy superimposed symbol line is mean blood pressure laboratory data during +2.25 Gz after 5 s at -2 Gz; light superimposed symbol line is the mean laboratory data for the same subjects during +2.25 Gz, after 2 s at -2 Gz.

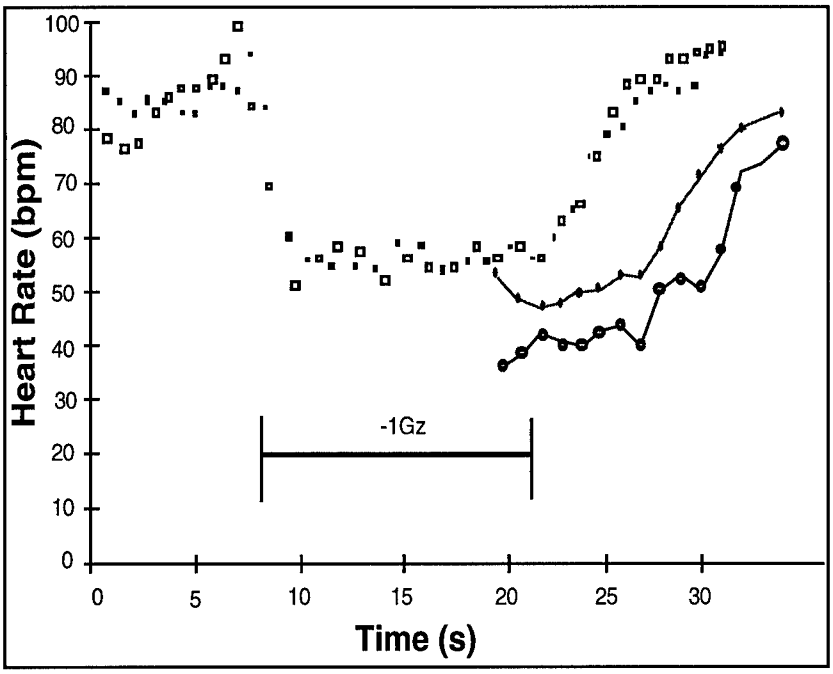

Figure 4. Recovery of blood pressure at +1 Gz after exposure to -Gz. Closed and open boxes are in-flight heart rate data for pilots A and B (from figure 1), respectively during maneuvers from +1 Gz, to -1 Gz, and to +1 Gz; light superimposed symbol line is mean blood pressure laboratory data during +2.25 Gz, after recovery from 10 s at -2 Gz; heavy superimposed symbol line is the mean laboratory data for the same subjects during +2.25 Gz, after recovery from 15 s at -2 Gz.

If these estimates are valid, exposures to -Gz less than 5 s would not allow time for full peripheral splanchnic and skeletal muscle vasodilation to occur. Under this circumstance, partial vasodilation results in a moderate increase in vascular volume space leading to a BP drop during +Gz, but not enough to overwhelm the HR-based compensation that occurs during +Gz.

When exposures to -Gz approach the postulated time to full vasodilation of 7-15 s, full relaxation of the peripheral circulatory bed results. Full vasodilation results in a greatly increased volume of vascular space, and profound drop in BP that can not be compensated for by increased HR alone. Full BP recovery is then dependent on the relatively slow vasoconstriction of the vascular system.

As mentioned earlier, two of the experimental subjects were older, and these two exhibited the least susceptibility to push-pull effects. If we assume that they had the normally expected decrease in arterial compliance (i.e., arterial stiffening) due to aging, then neither vasodilation nor vasoconstriction would have been prominent mechanisms in dealing with push-pull stresses. Rather, HR would have been the primary mechanism of recovery. With less ability to vasodilate, there would have been less BP liability during subsequent +Gz, and HR increase might have effectively ensured BP recovery. This may explain the apparent lack of push-pull effect in these two older subjects. Future aged-based analysis of experimental data is planned.

The role of cardiac contractility however, is unknown and difficult to postulate. Since BP maintenance is also dictated by CO (dependent upon cardiac filling), this issue will be explored in future studies using a new miniaturized nuclear cardiology biotechnology during simulated ±Gz.

CONCLUSION AND RECOMMENDATIONS

This analysis suggests that HR is the primary mechanism of response in push-pull effect when exposures to -Gz are less than 5 s duration. The slower responding vascular system becomes an increasingly dominant influence as the time at -Gz increases beyond 5 s. By 15 s of exposure to -Gz, recovery of BP is primarily determined by the speed of vasoconstriction of peripheral vascular beds.

Designing adequate protection for pilots will require understanding these mechanisms. Research on the response of the heart and vascular bed to short-term autonomic influence is indicated.

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SEIZURE ASSOCIATED WITH G-LOC: A POTENTIALLY FATAL OCCURRENCE

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INTRODUCTION

G-induced loss of consciousness (G-LOC) is a potential aeromedical catastrophe. Some pilots live to tell the tale (1), but over the last 15 years with the deployment of aircraft capable of rapid-onset high sustained +Gz there have been an increasing number of fatal fighter jet accidents which have been attributed to G-LOC (2). Recognition of unheralded G-LOC with rapid onset/high sustained G as a cause of aircraft accidents (3) has led to G-training programs in many NATO Air Forces which have been successful in reducing but not eliminating the occurrence of G-LOC accidents (2,4).

Whether or not a pilot recovers from a G-LOC episode in time to effect a recovery depends on a number of factors; situational - including aircraft altitude and attitude when G-LOC occurs, and physiologic - the duration of G-LOC and time to recovery of neural function sufficient to allow recovery of control or ejection.

The time to functional recovery following G-LOC has been studied by a number of investigators (5,6,7). Forster and Cammarota (8) found centrifuge subjects who experienced G-LOC had incapacitation times averaging about 12 seconds, from G-LOC to recovery sufficient to deactivate warning signals in the centrifuge. Recovery time for more complex behaviour including simulated trimming of aircraft power and acquisition of a target was longer, about 60 seconds. In a later study, Forster, Cammarota and Whinnery (9) found incapacitation times of 15-20 seconds in aircrew participating in a G-training program who experienced G-LOC. Incapacitation times varied somewhat depending on the type of G-exposure (gradual onset or rapid onset).

Houghton et al (10) found that performance as measured by choice reaction times and arithmetic computation tasks was degraded during the first minute of recovery from G-LOC and progressively improved over the next 2-3 minutes.

Although these studies provide information on the time to recovery of consciousness, there have been no studies which have monitored the ability of subjects to integrate the complex behaviour required to fly an aircraft following G-LOC. At DCIEM, Michel Paul has undertaken a study to measure subjects' ability to fly an aircraft simulator through a standard approach and landing immediately following an episode of G-LOC (11).

METHODS

Training for Canadian Forces (CF) fast-jet pilots includes a one day G-training program. Pilots are given lectures and shown videos on high-G physiology and ride the centrifuge through a series of acceleration profiles including gradual onset and rapid-onset runs, and optionally, a simulated air combat profile.

Subjects for this study were 29 pilots who participated in the G-training program. Participants came to the Defence and Civil Institute of Environmental Medicine (DCIEM) one day before their G-training program. Five were current on the CF18, 8 on the T33 and 15 on the CT114 Tutor, the CF basic jet trainer, either Instructor Pilots or recent graduates. One pilot was an ex-test pilot who was a few years out of a cockpit and therefore not current.

An ATC-610 instrument flying simulator was programmed to record 11 different flight parameters. The day prior to the G-training course, subjects practiced three iterations of a simulated 15 minute ILS task in the simulator. Outputs for 11 different flight parameters from the simulator were digitized and sampled through a computer and stored for analysis. The next day, all subjects repeated the simulated flying task immediately after egressing the centrifuge gondola. Further, subjects who experienced a G-LOC episode during G-training were retested a second time aprroximately 45 minutes post G-LOC.

Flying performance on the simulated instrument approach was assessed by calculating a Root Mean Square (RMS) error on the 11 flight parameters.

All pilots were monitored and videotaped during their centrifuge ride for G-training. A standard centrifuge profile was used for training (ASCC 61/51). This consists of a gradual onset run (0.1 G/sec) which begins with the pilot relaxed until peripheral light loss occurs, then initiation of the anti-G straining manoeuver to light loss or +9Gz, whichever occurs first. This run is followed by a rapid onset run (max onset capability of centrifuge from a 1.4 Gz baseline) to +6Gz for 30 seconds with G-suit inflation, or +5Gz/30 without a G-suit. A second rapid-onset run follows to 7G (without G-suit) or 8G (with G-suit) for 15 seconds. Whether or not a pilot wears a G-suit during training is determined by whether his current operational aircraft is equipped with a G-valve. A SACM (simulated air combat maneuver) profile is optional following the third ROR, with simulated 7, 8, and 9 G peaks for 10 seconds over a total 90 second profile.

Immediately on completion of the centrifuge run (within 5 minutes), pilots repeated the instrument flying task.

Paper presented at the Aerospace Medical Panel Symposium on "Neurological Limitations of Aircraft Operations: Human Performance Implications", held in Köln, Germany from 9-12 October 1995, and published in CP-579.

RESULTS

12 of the 29(41%) pilots experienced a G-induced loss of consciousness during their centrifuge training. The types of aircraft currently flown by the cohort, and the number and percentage of G-LOCs in each group is given in Table. 1

The 17 pilots who did not experience G-LOC completed the post-centrifuge flight simulation with no difference in performance compared with the previous day. Of the 12 pilots who did experience G-LOC, 11 also completed the simulated instrument flying task with no appreciable difference compared with their performance the previous day.

Table 1. Flying status of G-LOC pilots

CURRENT AIRCRAFT TYPE	NUMBER OF PILOTS	NUMBER OF G-LOC	INCIDENCE OF G-LOC
CF-18	5	0	0%
CT33	8	3	37.5%
CT114 TUTOR	15	8	53.3%
an ex-test pilot (several years removed from a cockpit and therfore not current on any a/c) also experienced a G-LOC.			

Table 2. Characteristics of G-LOC episodes

No.	Duration of G-LOC (secs)	Motor Activity (MA)	Duration of MA (secs)	Comments/Description
1	12	yes	8	bilateral synchronous extremity jerking; dreaming
2	6	no		
3	8	no		
4	10	yes	2-3	Dream; one extremity flail
5	6	no		
6	10	yes	2	dream; slight torso jerk
7	16	yes	2	torso jerk
8	8	no		
9	4	no		
10	5	no		
11	10	yes	2	torso twitch
12	9	yes	4	torso twitch

However, one of the pilots had considerable difficulty with the simulated flying task after G-LOC. He crashed the simulator on take-off. The simulator was reset in a flying attitude by the investigator, and the pilot went on to fly a very inaccurate and uncoordinated procedure turn. On the inbound leg, he failed to select the ILS frequency and went on to capture a VOR radial instead of the assigned ILS localizer because he failed to change frequencies. The task was terminated. 45 minutes later, he was retested and flew the entire sequence extremely well.

The videotape of each pilot experiencing G-LOC was reviewed to determine whether their were any unusual features. The duration of G-LOC, characteristics and duration of motor activity for the G-LOC pilots are given in table 2.

The pilot who demonstrated poor performance on the simulator had a longer period of G-LOC than all but one of the others, and his G-LOC episode was unusual in that he exhibited more motor activity with two cycles of bilateral synchronous extremity movement.

The clinical history of the unusual G-LOC pilot was reviewed. There was no family history of seizure, nor had the pilot ever experienced loss of consciousness previously. He had never experienced G-LOC in an aircraft. However, his encephalogram done during screening for aircrew selection was reported as "abnormal, type 6, paroxysmal." The report describes brief bursts of 7Hz theta activity which increased during hyperventilation, slowing to 3Hz with a paroxysmal form. He was then referred for a clinical neurologic review. There were no abnormal clinical neurologic findings, no family history of seizure disorder, and no history in the individual of febrile or childhood seizures. He was accepted for pilot training.

Screening EEGs on the other 11 G-LOC pilots were all classified as normal. A repeat EEG done on the unusual G-LOC pilot done several months after his G-training was interpreted as normal.

DISCUSSION

Despite increasing awareness of G-LOC and various remedial measures including G-training programs and improved G-protection, G-LOC continues to claim aircraft and lives. In many cases the scenario is such that the usual 12 to 15 seconds incapacitation time does not allow for recovery of control before ground impact. In other situations, however, the time constants for aircraft recovery are longer yet the pilot fails to re-establish controlled flight.

In this study of 29 pilots with 12 episodes of G-LOC during centrifuge training, all but one pilot demonstrated normal flying skills in a simulator immediately following the episode of G-LOC, certainly adequate to maintain control even in instrument conditions. One pilot, however, clearly was unable to maintain aircraft control in the immediate G-LOC period, and would in all likelihood have crashed even several minutes after his episode of G-LOC. The unusual features of his G-LOC episode were that it was longer, and characterized by bilaterally synchronous extremity motor activity. This occurred on a background of an abnormal screening EEG on enrollment which was characterized as "paroxysmal". Although not confirmed by EEG during his centrifuge run, it seems highly probable that this pilot suffered a seizure associated with his G-LOC episode, and that his poor performance on the simulator reflected a degree of post-ictal confusion. For discussion sake, he may be considered to have suffered a G-LOC/seizure, as opposed to a G-LOC/syncope which is the predictable occurrence of interruption of cerebral activity due G-induced ischemia.

There is little information on EEG data acquired during centrifugation, due at least in part to the technical problems presented. Lewis et al (12) monitored EEG output in 8 subjects who deliberately sustained G-LOC. No epileptiform activity was reported, although none of the subjects were reported to have extensive motor activity during G-LOC. Brent et al (13) reported that G-LOC was accompanied in all episodes by slow activity on the EEG.

Enthusiasm for the use of the EEG in screening aircrew candidates has waxed and waned since it was first initiated over 50 years ago, and its utility is frequently challenged and regularly scrutinized (e.g. 14,15,16,17). Some NATO air forces have abandoned routine EEG screening of aircrew candidates because of its low predictive value in predicting development of clinical epilepsy although a number still include it as case-finding screen e.g. asymptomatic aircrew applicants occasionally develop seizure activity during photic stimulation (18). Even in individuals with unequivocal epileptiform discharges on a screening EEG, the likelihood of developing an epilepsy is of the order of 2-% (19).

However, apart from the predictive value for future clinical seizure disorders, epileptiform activity on a screening EEG may be an indication of increased susceptibility to G-LOC/seizure as opposed to G-LOC/syncope. Early studies in WWII noted a correlation between the susceptibility of individuals to convulsive seizures following G-LOC and the presence of episodal activity on the resting EEG (21). ACM (air combat maneuvering) involves multiple physiologic stressors including not only +Gz, but potentially also fatigue, disorientation, hypoglycemia, hypoxia and hyperventilation. PPG (positive pressure breathing for G) is known to routinely induce hyperventilation (22,23), and hyperventilation and +Gz, both of which reduce cerebral blood flow, have long been known to be synergistic factors in producing G-LOC (10). So, although the predictive value of a screening EEG in aircrew is low for future unprovoked seizure events, the implications of an abnormal screening EEG in the multi-stressor environment of operational military flying may be quite different.

G-onset rates in current generation fighter aircraft produce G-LOC without warning, and physiologic stresses in future generation aircraft will be even greater. With these multiple combined stresses, individuals with paroxysmal or epileptiform discharges on their resting EEGs, while only slightly more prone to developing clinical epilepsy, may be at significantly greater risk of developing G-LOC/seizure, a surely fatal combination. These concerns provide further reason for retaining the screening EEG beyond the simple prediction of future clinical epilepsy. Future research on the utility of newer EEG techniques such as brain mapping and frequency domain analysis during G-LOC may be rewarding in terms of identifying individuals at risk of G-LOC/seizure.

In the meantime, aeromedical physicians who monitor acceleration subjects and aircrew during G-training should be alert to the possibility that some individuals who experience G-LOC, particularly prolonged G-LOC with bilaterally synchronous motor activity, may also be experiencing seizure activity and may require further investigation.

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TASK PERFORMANCE THROUGHOUT PROLONGED HIGH G EXPOSURE

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SUMMARY

Some ground-based research has investigated the loss of cognitive function in the extreme conditions of G-induced loss of consciousness (G-LOC), however, little is known about pilots' abilities to maintain cognitive performance throughout prolonged conscious exposure. Described herein is a centrifuge study in which human subjects repeatedly endured prolonged high-G simulated aerial combat to the point of peripheral light loss or physical exhaustion. Some profiles included over twenty plateaus at 9 Gz. Measures of cognitive and neuromuscular function, mental workload, and physiologic status were taken throughout the exposures, as well as neuropsychologic examinations after the exposures. Results indicate that more advanced protective systems not only allow longer endurance, but provide adequate support for maintained cognitive performance throughout the extended exposure. Although measures were affected by the type of protective system the subject was wearing as well as individual ability and coping strategies, consistent target tracking task performance, rapid recall decision reaction scores, and sufficient arterial oxygen saturation were maintained throughout extended exposures to a point preceding termination by only a second or two. No neuropsychological decrement was demonstrated post exposure. These results are encouraging, however, they are only a partial examination of situational awareness under extreme dynamic conditions.

INTRODUCTION

The recent deployment of positive pressure breathing for G (PBG) systems in the U.S. Air Force, as well as the pending deployment of advanced technology full-coverage anti-G suits, is resulting in greater physical endurance and, thus, longer duration high-G exposure [1]. Gz doses of greater than a million G-seconds are being anticipated [2]. Breathing pressures of 45 to 70 mmHg have been shown to increase G-tolerance time by increasing intrathoracic pressures, reducing the mechanical effects of increased G on respiration, and reducing the effort needed to perform straining maneuvers [3, 4, 5]. There have been only a few experiments concerning crew performance with these advanced suits in the military arena [6, 7, 8] and very little has been published in the open literature.

BACKGROUND

In 1944, the first experiment documenting impairment of cerebral function during exposure to G forces described subjects with confusion and momentary memory loss [9]. Frankenhauser's 1949 report documented increased reaction times to a multiplication task during 2-10 minute exposures to +3 Gz [10]. Canfield et al. in their 1949 investigation of vision under G showed increased reaction times to visual discrimination tasks during +3-5 G exposure for 15 seconds [11]. Chambers and Hitchcock demonstrated increased errors in a memory task during 90 second exposures at +6-7 Gz in 1963 [12]. In 1968 Little, Leverett, and Hartman also observed tracking decrements during accelerations of +5-9 Gz [13]. Piranian showed increased tracking error during exposure to +5 Gz [14]. Frazier et al., and Darwood et al., both in 1990, showed increased error in time and weight estimation tasks, respectively, during long duration centrifuge exposure but only up to +4 Gz [15,16]. Albery et al. used a maze solving task [17] and then later used a dual tracking task [18] and documented a decreased performance with increased G stress over a 60 second period.

In contrast, there are several studies that have shown no sig-

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nificant performance decrement under G. Canfield, Comrey, and Wilson in 1948 found no effect on a memory matching task during exposures up to +5 Gz [19]. Again in 1950, Canfield et al. had consistent performance up to +5 Gz on a visual reaction time task [20]. Creer found no tracking task decrements at any acceleration level up to 6 Gz for 2.5 minutes using a heavily damped control task. Between +6 and +9 Gz, performance dropped rapidly, attributed primarily to the serious visual degradation occurring above +7Gz [21].

Grether reviewed the effects of acceleration on performance, and concluded that simple and choice reaction times to visual signals generally increase during increased levels of +Gz. However, these effects tend to diminish or disappear as humans become more accustomed to acceleration environments [22].

Another very important factor, is the lack of standardized G profiles and exposure times. Seat geometry, centrifuge gimbal geometry, onset capabilities, and G gradients resulting from various centrifuge arm lengths, all combine to make results from various experiments difficult to compare [23]. In addition, tremendous variability in the backgrounds, training, ability, and motivation of subject participants has created a wide range of results [24].

The study of cognitive performance during prolonged 3-4 minute conscious exposure to very high G levels (+9Gz) has only recently become necessary with the deployment of advanced protective equipment. Some research has investigated the loss of cognitive function in these extreme conditions as related to G-induced loss of consciousness [25,26,27,28] but little is known about the effect on task performance during continuous conscious exposure to high G.

APPROACH

Studies conducted prior to 1980, and cited above, limited the stress to lower G levels and short durations. During the early 80s it became obvious that the new generation of fighter aircraft were being used in conditions of sustained 7 and 8 Gz and, in some configurations, 9 Gz. As G-LOC awareness grew, research and training focused on prevention and/or detection of G-LOC. Through improved pilot technique at the anti-G straining maneuver and, more recently, improved protective equipment, the 1990s has become the decade of prolonged exposure to high sustained acceleration. The approach taken in the study described herein was to allow centrifuge research subjects to endure prolonged exposure and continuously measure their cognitive performance. A multiple task paradigm was used in which subjects were performing a primary target tracking task while simultaneously monitoring a rapid choice reaction task. Subjects were asked to continue in an alternating 5 to 9 Gz profile until they lost their peripheral vision or until physical exhaustion.

In addition, the optimal configuration of the advanced protection system was still an issue, and thus the study was repeated with each subject wearing six different protective system configurations.

METHODS

An open-loop primary tracking task, with the Rapid Communication (RapCom) secondary task superimposed, was presented on a 175 degree horizontal by 60 degree vertical field-of-view visual display inside the centrifuge cab. Subjects underwent alternating +5Gz to +9Gz peaks with 5 sec plateaus until peripheral light loss or physical exhaustion. Two neuropsychological measurement tools (Stroop and PIN tests), known to be sensitive to neurological compromise in brain damaged individuals and stroke victims, were used post-exposure to determine any neurological decrement. Pulmonary function tests were also conducted pre- and post-exposure for suit condition effects. Oxygen saturation values were collected during all high-G exposures via a Nellcor Pulse Oximeter. Subjective ratings concerning workload and suit conditions were also elicited from the subjects.

Six anti-g suit conditions were evaluated under this simulated air-to-air combat task. They included:

1) standard issue CSU-13B/P air-filled suit
2) standard suit with the current Combined Advanced Technology Enhanced Design G Ensemble (COMBAT EDGE)
3) Advanced Technology Anti-G Suit (ATAGS)
4) ATAGS with COMBAT EDGE
5) Advanced Protection System (APS) full-coverage air-filled suit developed by Northrop
6) Atlantis Warrior full coverage water-filled suit developed by McDonnell Aircraft

RESULTS

The mean number of +9 Gz peaks subjects endured in each suit condition are shown in Figure 1 and were as follows:

1) standard suit = 4.2
2) ATAGS = 5.3
3) standard with COMBAT EDGE = 7.3
4) Atlantis Warrior = 7.8
5) APS = 13.0
6) ATAGS with COMBAT EDGE = 15.2

The standard suit and ATAGS were statistically comparable in terms of G-endurance, followed in increasing endurance by the standard with COMBAT EDGE and the Atlantis Warrior, which in turn were followed by the APS and ATAGS with COMBAT EDGE. The Stroop and PIN neurological tests showed no effects concerning suit condition, but did show very large order effects; as subjects obtained repeated exposure to these tests, performance increased. This suggests these types of tests should not be used in repeated measures experimental de-

signs in the future. Oxygen saturation decreased as time at high-G increased. Results of the pulmonary function tests showed that reductions in lung volumes were surprisingly minimal across most suit conditions.

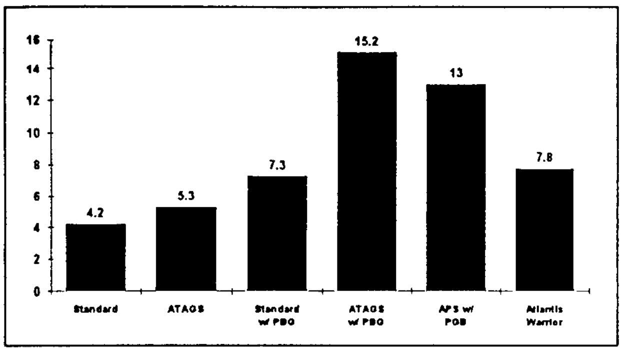

Figure 1. Mean number of +9Gz peaks endured. Minimum significant difference = 7.3 peaks.

The Subjective Workload Dominance (SWORD) questionnaire showed increased ratings of workload as the number of 9Gz peaks endured increased. In addition, the standard suit alone generated significantly higher workload ratings than any of the other suit conditions.

Reasons given for exposure termination were expressed as shown in the following table:

Reason	Incidence	% Total	
Peripheral Light Loss	27	31	
Exhaustion/Fatigue	23	26	71 %
Central Light Loss	12	14	
Breathing Problems	12	14	
Arm Pain	6	7	
Leg Pain	6	7	
Neck Pain	1	1	
Straining Problems	1	1	

Subjects sometimes showed an early period of task decrement, but then returned to consistent performance for long periods. As shown in Figure 2, this typical prolonged exposure resulted in the subject maintaining good, consistent performance up to the last high peak before termination. Thus after 19 to 22 peaks of +9Gz exposure, this subject was still performing at or better than performance at exposure initiation.

Further analysis was completed in order to fully characterize the interactions of suits with strategies and G effects. This data analysis was focused on the sensitivity of the performance metrics to effects of training, fatigue, strategy, and the wide range of subject ability. Results indicate that well trained and protected subjects will maintain both primary and secondary tasks with consistent performance throughout the exposure with infrequent catastrophic failure occurring fairly suddenly at the end. Initially (over the first three 9Gz peaks), no significant

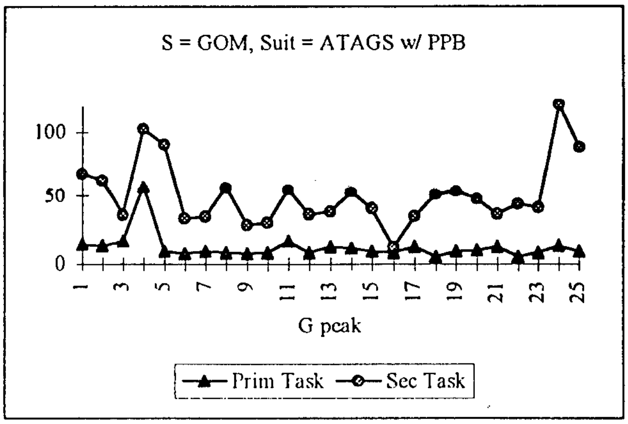

Figure 2. Tracking and RapCom performance over prolonged high G exposure.

effects of suit conditions were found, however, positive pressure breathing (PBG.) configurations provided better performance than non-PBG. Some subjects never performed at the level of the best subjects and coping strategies varied widely. Although performance of both primary and secondary task was decremented by Gz exposure (compared to unstressed performance), some subjects were affected adversely by G onset and 9 Gz peak while others performed best at these times and rested during the offset and 5 Gz plateaus. Thus, due to confounds, no isolated effect of G level or profile segment on performance could be tested.

CONCLUSIONS

No significant effects of anti-G protection suit on task performance were found during the first 90 seconds of acceleration exposures, some up to 9G. As non-PBG suit conditions dropped out, after approximately three exposures to 9G, PBG suit conditions continued to produce effective primary and secondary task performance, sometimes out to 22 peaks to 9G. This experiment supports the use of PBG anti-G protection and the incorporation of full coverage anti-G trousers, such as the ATAGS. Such a combination reduces the physical effort pilots of high performance aircraft have to exert in order to fly at high G, thus reducing pilot workload. Reduced workload allows the pilot more time to manage cockpit and flying tasks.

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CERVICAL SPINAL CORD INJURY TOLERANCE UNDER +Gz ACCELERATION

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SUMMARY

Experimental manikin ejection data from the U. S. Naval Air Warfare Center was analyzed using a multimodality biomechanical approach to investigate the consequences that helmet mounted devices and improper head positioning have on the cervical spinal cord during ejection from high performance aircraft. Accelerations of the head center of gravity from the manikin studies were compared to a physical model of the head-neck complex run under similar conditions. Strain and strain rates in the cervical spinal cord obtained from this biofidelic physical model were compared to the functional tolerances of isolated myelinated axons, crustacean spinal cords, and isolated neurons. If the strain and strain rate exceed the isolated tissue and cell culture critical threshold levels (>15% and $1s^{-1}$, respectively), altered calcium homeostasis and electrophysiological dysfunction occur.

Results suggest that moving the combined head-helmet center of gravity forward and positioning of the head improperly during ejection increase the possibility of neurological deficit and that the cervical spinal cord must be considered in evaluating the feasibility of egress procedures.

INTRODUCTION

Since the first aircraft ejection almost five decades ago, many researchers have investigated the response of the head-neck complex to impact acceleration in order to develop the safest egress procedure possible. After the revolutionary studies of Stapp (1) on human volunteers undergoing rapid acceleration, many investigators have shown how the human and human surrogate head-neck complexes react to acceleration in both the *Gx* and *Gz* directions (2-7). Most recently, Wismans *et al.* (8-10) have investigated the response of cadavers to acceleration forces and developed a model to predict head-neck motion. Researchers, such as McElhaney *et al.* (11, 12), have described vertebral fracture and cervical disk deformation in isolated cervical spinal cords due to a variety of loading conditions while others have looked at the mechanical properties of the ligaments (13) and muscle forces in the cervical spine (14).

These investigations have led to the development of injury predictors and tolerance levels such as the Dynamic Response Index and the Guidelines for Safe Human Experimental Exposure to Impact Acceleration (15). In these reports, fracture of the bones, dislocation or sublaxation of vertebral bodies, herniation of discs or fracture of disc endplates, avulsion of ligaments, and disruption of blood vessels, internal viscera or supporting ligaments that result in any chronic impairment of health are considered unacceptable. Although these reports have considered the forces and moments necessary to cause these types of trauma and disruption of hard tissue, they have not considered what effect acceleration impact, such as an ejection, has on the cervical spinal cord.

Injuries such as transient neuropraxia and SCIWORA (Spinal Cord Injury WithOut Radiological Assessment) are two types of clinical cervical spinal cord injury that cause neurological impairment without ligament or hard tissue damage. Previous research done in our laboratory suggests that these types of injury can occur during traumatic hyperflexion of the neck and that increased head acceleration increases the probability of these injuries (16). Because hyperflexion has been shown to occur during ejection (17), there exists a possibility of these types of injury during ejection. Additionally, moving the head-helmet center of gravity (CG) forward, i.e. helmet mounted systems, and increasing the initial angle between the seatbox and the back of the pilot's head, i.e. improper positioning, will increase the head CG acceleration during ejection.

This study investigates the neurological implications of helmet mounted devices and improper head placement during ejection from high performance aircraft.

MATERIALS AND METHODS

In order to evaluate the effect of helmet mounted devices and poor head positioning on the cervical spinal cord during ejection, a multimodality biomechanical approach previously used in our laboratory was employed. This cyclic approach focuses on preventing traumatic central nervous system tissue injury in the head-neck complex due to inertial non-impact forces by utilizing both macroscopic and microscopic techniques (Figure 1).

The ejection profile for a particular ejection serves as the loading conditions for either manikin or volunteer tests on an ejection tower or acceleration sled. From these tests, the appropriate accelerations and/or forces acting on the head-neck

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complex are obtained. These head accelerations and/or forces are then compared to a biofidelic physical model representing the head-neck complex, including the central nervous system, run under similar conditions. Data from this biofidelic model give information about the strains and strain-rates that are seen in the spinal cord during ejection. Next, isolated tissue and cell culture studies are conducted under similar deformations. From the functional responses generated in these microscopic studies, the probability for cervical spinal cord injury during the ejection can be determined. At this point, improvements should be made to the escape system which would decrease the chance of cervical spinal cord injury occurring under $+Gz$ acceleration.

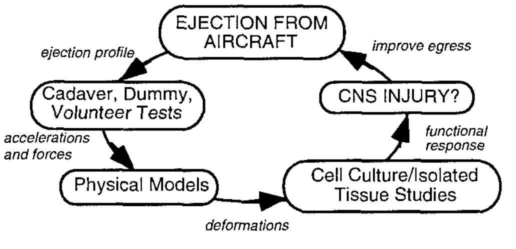

Figure 1. Multimodality Biomechanical Approach

Physical Model

The physical model used in this study was developed in our laboratory by Bilston (16) for investigation of the deformation in a surrogate spinal cord during rapid head accelerations such as hyperflexion and hyperextension. The brain tissue and spinal cord surrogates are composed of a mixture of Sylgard 527 and 184 gels (Dow Corning Inc.) that match the viscoelastic properties of these tissues at high strain rates. Grid marks are placed within the gel in order to allow for measurement of deformations. These surrogates are placed within anatomically accurate plastic head-neck models (Carolina Biological Supply Co.) which simulate the vertebral column and skull. This head-neck complex is attached to a mounting can which is connected to a modified pneumatic linear actuator (Consolidated Vacuum Corp.). A custom designed linkage converts the linear actuator motion to an angular motion of approximately 65 degrees. Acceleration of the CG was recorded using a piezoelectric accelerometer-charge amplifier-digital system (Endevco 2220D). By varying the pressure in the actuator cylinder, the acceleration of the center of gravity of the model can also be varied. For hyperflexion, this model was run at a load pressure of 125 psi and at a set pressure of 25 psi.

Using high speed digital video photography (Kodak Ektapro EM Motion Analyzer), which records the motion of the physical model at 1000 frames per second, the strain and strain rates in the spinal cord surrogate can be determined by digitizing the movement of the grid marks from frame to frame.

Validation of this model was accomplished by comparing the quasi-static deformation of the spinal cord and rotation of the vertebral bodies in the physical model to similar quasi-static motions in human volunteers. *In vivo* cervical spinal cord displacements and vertebral rotations were measured noninvasively by Margulies *et al.* (18) by using a tagged snapshot motion-tracking magnetic resonance imaging technique. It is interesting to note that these *in vivo* studies confirmed the work of Breig (19) on cadavers which showed that the spinal cord deforms and moves in relation to the vertebral bodies even during quasi-static motion.

Anthropomorphic Test Dummy

A 50th percentile male Hybrid III manikin with a 50th percentile Hybrid II head, modified with a head fixture to vary head weight and the combined head-fixture CG, was placed in a GRU-7 ejection seat on the NAWCADWAR ejection tower. This manikin was restrained with a U.S. Navy MA-2 torso harness and subjected to a 15 $\pm$0.5 Gz ejection catapult pulse. The manikin head was instrumented with linear accelerometers (Endevco 2262A-100) in the Gx and Gz as well as an angular accelerometer (Endevco 7302B) in the pitch axis. The manikin thorax and ejection seat were each instrumented for linear acceleration (Endevco 2262A-50) in the vertical axis. The data was filtered at 200 Hz, sampled at 1KHz, and processed using an 11 point moving average.

To model the effect of helmet mounted systems, a novel head fixture was used which changes the head-helmet CG while increasing the weight. This fixture weight is 1.5 lbs. and an additional 1.5 lbs. (0.75 lbs. added to each lateral attachment point) was added to the fixture to result in a baseline weight of 3.0 lbs. To each of the four locations on the center mounting bar of the fixture (roughly 0°, 30°, 60°, and 90° relative to a posterior to anterior axis through the occipital condyles) additional weights of 1.1, 2.1, 3.1, and 4.1 lbs. were added to bring the total added head weight to 4.1, 5.1, 6.1, and 7.1 lbs. A spacing of 1 inch was maintained between the headbox and the back of the manikin's head by either a pad or a low tensile string.

In studying the effect of improper head positioning during ejection, the 6.1 lb. configuration at the four different locations was used. Initial gap distances between the seatbox and manikin head were maintained at 0.9, 2.1, and 3.3 inches by either a pad or a low tensile string.

For the purpose of this study, only the Gx head CG will be analyzed because it is the only necessary parameter for comparing the manikin studies with the physical model. Furthermore, it is assumed that the head remains in the sagittal plane during all of the manikin runs.

RESULTS

Physical Model

Figure 3 compares the Gx head CG acceleration traces for the physical model with Ewing's human volunteer data (2) and Wismans cadaver data (10). For the physical model, the peak G level is 40 g's and the time to peak acceleration is 10 ms. Analyzing the cervical spinal cord deformation from the high speed video photography resulted in maximum peak strains of

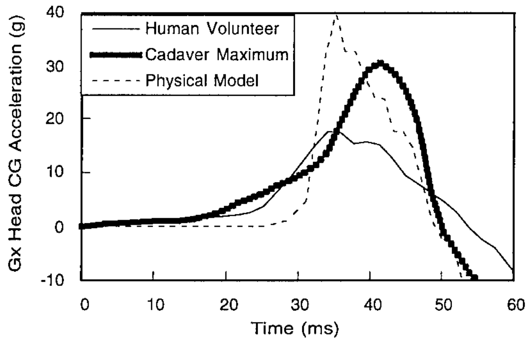

Figure 3. Acceleration traces of the CG of the head for the physical model, Ewing's volunteer data, and Wismans' cadaver data

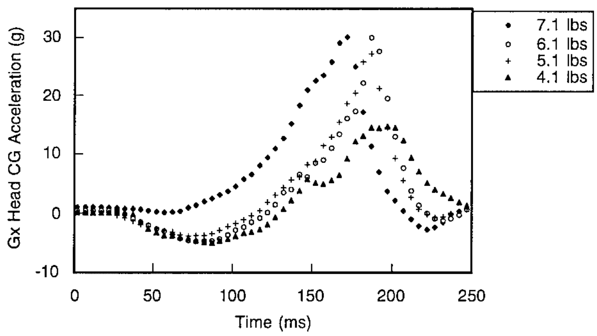

Figure 4. Acceleration traces for manikin run with constant initial gap and added weight to position one (0°)

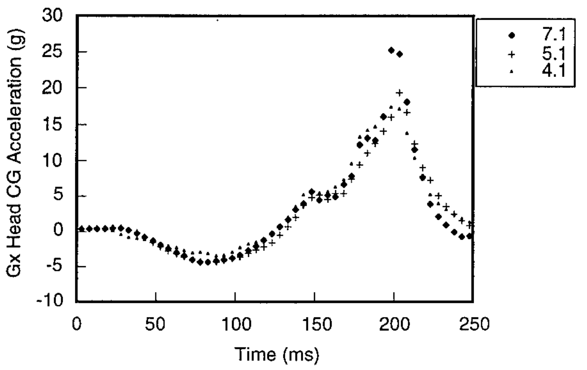

Figure 5. Acceleration traces for manikin run with constant initial gap and added weight to position two (30°)

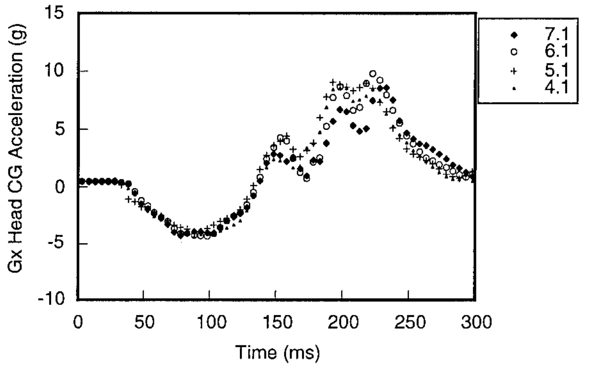

Figure 6. Acceleration traces for manikin run with constant initial gap and added weight to position three (60°)

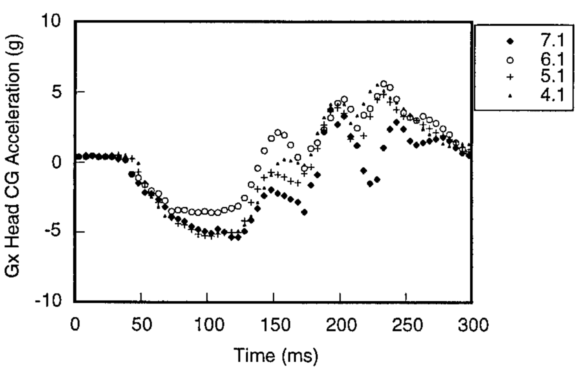

Figure 7. Acceleration traces for manikin run with constant initial gap and added weight to position four (90°)

35% in the upper middle cervical spinal cord (C3-C5) with strain rates ranging from 5-15 s^{-1} (16).

Anthropomorphic Test Dummy

Effect of Changing CG While Adding Weight

Figures 4 through 7 show the *Gx* head CG acceleration time histories for each of the four locations of the head-helmet device each with four different weights and a constant seatbox - head initial separation.

Table 1 shows the peak head CG accelerations for each of the 16 configurations. As can be observed, the peak G level increases with the movement of the center of gravity forward and with increased helmet weight resulting in a maximum G level of 28 g's in the most extreme case. It was determined that the effect of changing the location of the center of gravity on peak G level was significant (F-ratio = 28.8) and the effect of additional weight on peak G level was not significant (F-ratio = 1.4; Two-Way ANOVA, 95% confidence).

		Total Helmet Weight (lbs)			
		4.1	5.1	6.1	7.1
CG	0°	14	26	27	28
Position	30°	17	18	19	23
	60°	8	8	9	8
	90°	5	4	5	3

Table 1. Peak manikin Gx head CG acceleration (g's) for a constant initial gap distance with changing CG while adding weight

Effect of Increasing Forward Initial Head Position

Figures 8 through 10 represent the *Gx* head CG acceleration time histories for each of the three initial distances between the seatbox and manikin's head keeping the total helmet weight constant (6.1 lbs) but varying its CG.

Table 2 shows the peak head CG accelerations for each of the 12 configurations. From this table, it is evident that the peak G level increases with increased gap distance and with forward movement of the center of gravity. It was determined that the effect of increasing the gap distance on the peak G level was significant (F-ratio = 13.2) and the effect of changing the location of the center of gravity on the peak G level was also significant (F-ratio = 13.0; Two-Way ANOVA, 95% confidence).

		Initial Gap Distance Between Seatbox and Manikin Head (in)		
		0.9	2.1	3.3
CG	0°	27	29	32
Position	30°	19	27	32
	60°	9	17	28
	90°	5	7	23

Table 2. Peak manikin Gx head CG acceleration (g's) for a constant weight configuration with varying gap distance and CG position

DISCUSSION

Comparing the *Gx* acceleration traces of the CG of the head for the worst case scenario manikin run in the helmet mounted systems study (helmet weight of 7.1 lbs with the center of gravity shifted forward - Figure 4), with that of the physical model run in flexion (Figure 3), it can be seen that the maximum G level of the manikin head is 12 g's lower than the peak model acceleration and the time to peak acceleration is between five and six times longer.

Comparing the *Gx* acceleration traces of the CG of the head for the worst case scenario manikin run in the improper head position study (initial gap distance between seatbox and manikin head of 3.3 inches with center of gravity moved forward - Figure 8), with that of the physical model run in flexion (Figure 3), the maximum G level of the manikin head is 7 g's lower than the peak model acceleration and once again the time to peak acceleration is five times longer.

Previous studies performed in our laboratory investigating the effects of dynamic elongation on axons of the frog peripheral nerve, squid giant axons, and crustacean spinal cords have shown that strains in excess of approximately +15 percent at

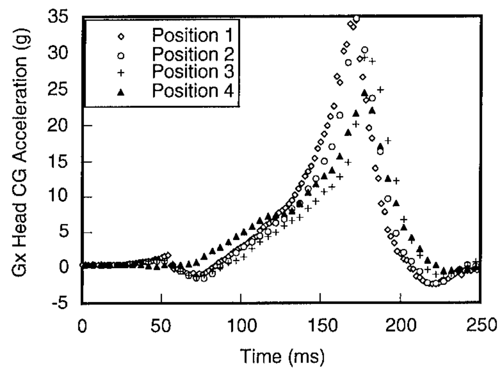

Figure 8. Acceleration traces for manikin run with 6.1 lb configuration, initial gap distance of 3.3 in, and varying CG

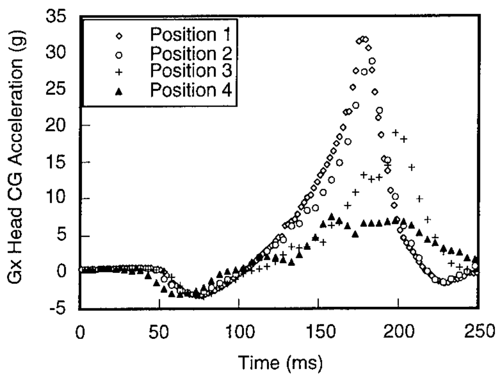

Figure 9. Acceleration traces for manikin run with 6.1 lb configuration, initial gap distance of 2.1 in, and varying CG

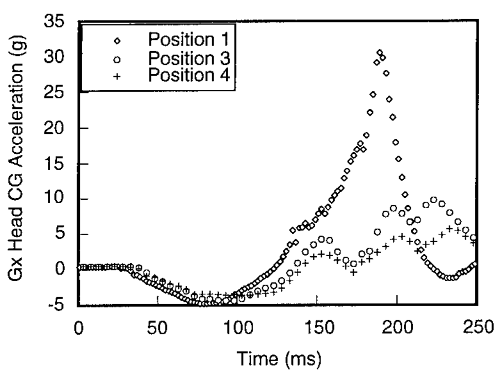

Figure 10. Acceleration traces for manikin run with 6.1 lb configuration, initial gap distance of 0.9 in, and varying CG

strain rates in excess of 1-5 s^{-1} can result in altered calcium homeostasis and transient or permanent electrophysiological dysfunction such as the loss of the ability to transmit action potentials. However, if the strain rate is less than 1 s^{-1} for a +15 percent strain these neurological deficits do not occur (20-22). Additionally, neuronal cell culture studies (NT-2 cell

line) are currently being conducted in our laboratory. Results show a similar strain and strain rate dependent threshold for altered calcium homeostasis.

In similar experiments by our laboratory investigating diffuse axonal injury in primates, gel physical models of the primate brain and skull revealed that the location of strains in excess of 15% with strain rates greater than $1s^{-1}$ were highly correlated to the location of functionally impaired tissue as shown by histological slices (23).

Comparing strain and strain rates from the physical model (35% and 1-5 s^{-1}, respectively) to the threshold numbers described above for altered calcium homeostasis and electrophysiological dysfunction in the microscopic studies suggests that during this traumatic flexion of the neck the tensile deformation of the spinal cord may be sufficient for neurological deficit.

Because the hyperflexion physical model was only run at one pressure setting resulting in a 40 G peak level with a 10 ms rise time to peak G, it cannot be exactly stated what the strain and strain rates will be in the cervical spinal cord in each of the manikin ejection simulations. However, certain observations and predictions can be made.

As stated above, it has been previously shown through isolated tissue and cell culture studies that the strain rate plays a significant role in determining nervous system tissue dysfunction. At low strain rate levels, the tissue studies showed axons having no dysfunction up to 40 percent strain (22). For example, a 14 - 19 percent strain in the middle cervical spinal cord region can be observed *in vivo* during flexion (18). Injury, however, does not occur because during this quasi-static motion the strain rate is insignificant Thus for all of the manikin runs, it can be predicted that the peak strain will be above 19 percent, the highest quasi-static strain.

Because a strain of 19 percent has been established to be sufficient to cause injury at high strain rates, it is of paramount importance to asses the equivalent strain rate in the spinal cord during each manikin run. Although the physical model was run at only a single G level for hyperflexion, it was run under different G conditions in hyperextension. Trends in this hyperextension data suggest that as the peak G level increases the strain and strain rates seen in the cervical spinal cord also increase (16). Thus for similar times to peak G level, it is assumed that as the peak G level increases in hyperflexion, the strain and strain rate will increase and thus the probability of injury.

Using the peak Gx head CG acceleration as a predictor for cervical spinal cord injury, it can be observed from Table 1 that the probability for injury greatly increases as the CG of the head-helmet complex is moved forward. From the statistics, the position of the CG is more important than the weight of the helmet. Due to its inertial effects, however, the helmet weight should be kept to a minimum. From the data in Table 2, it can be inferred that as the distance between the seatbox and manikin head increases, the risk of injury also increases. In this case, both the positioning of the CG and the distance away from the seatbox are significant in increasing the peak head CG acceleration level.

It should be noted that the manikin head-neck complex has been shown to be stiffer than that of either cadavers or human volunteers during dynamic loading (8). This increased stiffness may falsely predict a longer time to peak G level and thus a strain rate lower than one that would be seen *in vivo*. From Figure 3 it can be observed that the time to peak G level for both the human volunteer and cadaver is a little over 10 ms. One reason for this shorter time to peak G level as compared to the manikin time to peak G of 60 ms is that volunteer and cadaver experiments were run on a horizontal acceleration sled as opposed to an ejection seat. On the horizontal acceleration sled, the acceleration pulse is perpendicular to the body Z axis (cephalad to caudal), which causes the head-neck complex to rotate immediately due to inertial effects which attempt to keep the head in its previous position. If the ejection pulse were in line with the CG of the head no rotation would occur. Because the CG of the head is more rostral than its attachment point to the cervical spine at the occipital condyles in a normal seated position, an impulse delivered directly to the body Z axis will cause rotation of the head-neck complex and the time to peak G level will be longer due to the inertial properties of the head. It is these differences in moments of inertia of the head-neck complex (relative to the sternoclavicular joint) that give rise to the initial negative acceleration and the undulation of the acceleration trace in some of the graphs representing the manikin runs.

CONCLUSION

Using this biomechanical systems approach, it is clear that the probability for injury greatly increases when helmet mounted devices are worn and when a pilot ejects with improper body positioning. It is paramount that as ejection seats improve and more devices are added to the helmet that researchers investigating safe egress procedures consider cervical spinal cord injury and thus neurological dysfunction as one of the limiting factors.

This paper describes how a multimodality approach can be implemented to evaluate the feasibility of different egress procedures. This approach determines the effect that macroscopic forces, such as those seen during ejection, have on the microscopic world of the cell. Because this is only a preliminary study, additional tests must be conducted. More physical model tests must be run in order to establish an empirical relationship between peak G level and the strain and strain rates observed in the cervical spinal cord. Additionally, male and female cadaver tests should be run in order to identify any gender differences in head-neck complex response to impact acceleration.

ACKNOWLEDGMENTS

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thanks to the United States Naval Medical Research and Development Command for use of the manikin NAWCADWAR ejection tower data.

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THE USE OF FINITE ELEMENT MODELING TO EVALUATE DISEASED SPINAL COLUMNS FOR AIRCRAFT EJECTION SAFETY

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INTRODUCTION

A great deal of work has been accomplished analyzing ejection seat acceleration profiles and their effects on normal, nondiseased spinal columns in aviators. Considerably less work has been accomplished on the effects of aircraft ejection on diseased spines, which are, in fact, quite common in the flying community. This study was an attempt to address this concern and specifically to evaluate a particular mathematical model for accuracy in predicting whether specific spinal diseases or geometries will enable safe aircraft ejection without further spinal injury.

Pilots ejecting from early aircraft ejection-seat systems had approximately a 12% incidence of vertebral fractures. The newer ejection systems have a lower maximum acceleration force in the G_z^+ direction and also a considerably slower G onset and are generally safe for the typical pilot (adult male) without spinal disease when the pilot ejects within the envelope (altitude, speed and attitude limitations). But if a surgical procedure is done on the spine, e.g., a laminectomy, hemilaminectomy or cervical fusion, there may be a decrease in the overall strength of the spinal column, leading to a fracture or dislocation of vertebrae, disk herniation, or even spinal cord injury during ejection.

Extensive previous work, including animal modeling and mathematical modeling, much of which has been performed by the Crew Systems Directorate at Wright-Patterson AFB, addresses this issue for the nondiseased spine. When a pilot ejects from an aircraft in a typical ejection seat, his vertebral longitudinal axis is approximately in line with the rails on the back of the seat, which is the direction of thrust (Figure 1).

Figure 1.

Therefore, the direction of forces is essentially in line with the vertebral axis. Also, because the adult spine has a kyphotic and lordotic curvature, there are force vectors other than perpendicular in relation to the vertebrae.

METHODS

This model focused on a small part of a single vertebra. We used finite element analysis to model this vertebra. Using this computer modeling technique, a complex geometry is broken down into a

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composite of many small, simple geometries connected together, thereby enabling the analysis of stresses and strains. As a model, we made it extremely simple and tried to validate it with respect to the properties of the biomaterials involved, which, of course, in the human body are extremely complex.

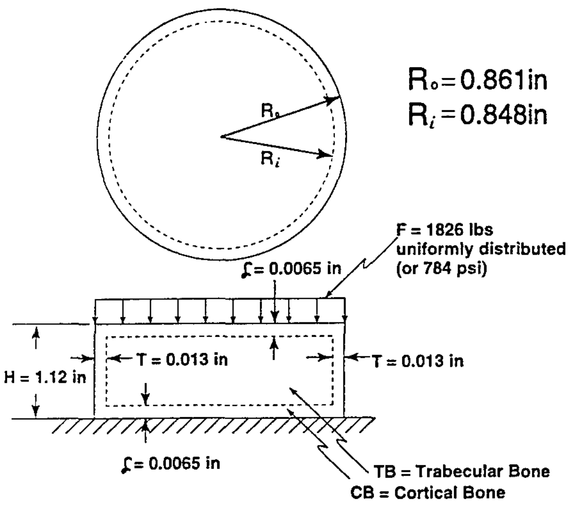
Most of the appplications using the finite element technique have been performed on nonbiological materials, such as connecting rods and crankshafts. The properties of these nonbiological materials are much simpler, being fairly homogeneous and isotropic with small, linear elastic displacements. In contrast, the spinal colomn is a composite material consisting of several nonlinear, viscoelastic, anisotropic components which undergo large displacements (Table 1). For this reason, the accuracy of the model had to be assessed to assure it provided accurate predictions of the true stresses and strains which occur internally when external loads were applied to it.

Using the USAF Waiver File, we identified individuals with spinal disease. We compared this data set with that from the USAF Safety Center database consisting of all individuals who had ejected from aircraft. We then compared dates for the spinal disease waivers and aircraft ejections for each of the aviators to determine all those who ejected after obtaining a waiver for spinal disease. Only one individual was identified. This aviator was a male RF-4C (F-4 reconnaissance, C model) pilot who underwent hemilaminectomy of the fifth lumbar vertebra (L5) in 1975. He recovered without complications, and in 1978 at the age of 25, he ejected from an RF-4C in a Martin-Baker seat. During this ejection he suffered no back injuries. We used the finite element technique to simulate this ejection, determining whether the model predicted the same results, i.e., no stresses exceeding the maximum stresses which a vertebra can tolerate without fracturing.

The specific material properties used are shown in Table 2. These are the ultimate compressive stresses for the outside cortical bone and the inside trabecular bone. Specifically, one wants to assure that in this model the maximum compressive stresses which are developed when G loading occurs do not exceed the ultimate compressive stress for the particular type of bone because, at this ultimate compressive stress, a fracture is predicted to occur.

We obtained anthropometric data to estimate the proportion of body weight which is above the L5 vertebra, which is about 73% (1). This percentage was multiplied times the aviator's body weight. To this weight we added the weight of the helmet, mask and shoulder harness. (The parachute pack usually does not produce a load on the spine as it rests on the the seat directly behind the aviator.) The maximum G exposure for an individual of this weight during ejection in a Martin-Baker ejection seat is approximately 14 Gs (2). The model is shown in Figure 2.

FEM Model: Vertebral Body After Laminectomy



Material Properties:

Modular of Elasticity of:	Poisson's Ratio:
CB: 2.18×10^6 psi	CB: 0.25
TB: 1.07×10^4 psi	TB: 0.25

Assumptions: Linear, Elastic

WILLIAM E. DREW, LTC, USAF, MC, FS
040-50-2345/AFSC 9356, 9576
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Figure 2.

RESULTS

This model predicts that during this ejection the maximum compressive stress is 13,300 pounds per square inch (psi). The location of maximum stress is at the center of the top surface of the vertebral body in the cortical bone, far less than the ultimate compressive stress of 29,000 psi.

SUMMARY

These results are consistent with the finding that the individual did not suffer injury because the maximum compressive stress did not exceed the ultimate compressive stress for bone. Therefore, this simulation predicts that no vertebral fracture would occur, which, in fact, is consistent with that observed in this ejection. Thus, this very simple model provides a reasonably accurate assessment of the stresses which occurred during this particular ejection.

CONCLUSION

Further validation of this model is needed, to include analysis of intervertebral disks, which were not addressed in this study. In the future we hope to perform analyses of modifications of this model to include cervical fusions, various types of degenerative disk diseases, osteoporosis, etc. Animal modeling also will provide further model validation.

There are a great many future applications for this technique. At the Aeromedical Consult Service, we evaluate aviators with specific spinal diseases, including individuals with herniated disks, spinal surgery, and degenerative disk disease. We plan to further develop and validate this and other finite element models to enable the individual assessment of aviators with specific spinal diseases to assure that they can safely eject from their aircraft prior to returning them to flying status. We need to assure that the given ejection seat designs are optimal throughout the range of weights and body sizes for all aviators, both men and women, who will be flying them. Also, we hope to apply this model to ejection systems in future aircraft designs which potentially could have larger G exposures either during flying or ejecting. Similarly, new helmet and parachute designs may be evaluated for their effects on spinal loading prior to final design and production.

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TABLE 1.

Differences with biologic materials

Significant variation in material properties

Larger deformities

More complex and variable geometries

Viscoelastic behavior

Deformities are time dependent

Anisotropy

Numerous different contiguous materials(bone, ligament, tendon, blood, blood vessels)

Material properties change over time

TABLE 2.

Finite Element Model Data:

2 Homogeneous, isotropic linearly elastic materials: cortical bone(CB) outside and trabecular bone(TB) inside:

	Cortical Bone	Trabecular Bone
Modulus of elasticity:	2.18 X 10**6 psi	1.07 X 10**4 psi
Poisson's Ratio:	0.25	0.25
Ultimate Compressive Stress:	29,000 psi	667 psi

(References: Park; Plesha;White)

Hypoxia induced impairment of granulocyte function

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Abstract: Adequate resistance to infections depend upon, among other factors, the phagocytic capacity of polymorphonuclear neutrophilic granulocytes (PMNL). It is well documented that hypoxia stimulates the formation of red blood cells. But this study, together with some early works, indicate that hypoxia might stimulate the hematopoietic system in general, not only the eythropoietic cell lines. Hypoxia may interfere with ATP-dependent cell function. Intermittent or chronic exposure to hypoxia could therefore adversely affect resistance to infections.

Rats were exposed to repeated hypobaric hypoxia (0,5 atm) for 17 hours per day for 0-7 days. This induced a significant reduction of the phagocytic capacity of the neutrophil granulocytes in addition to an increase in hematocrit, haemoglobin, thrombocyte, and total leukocyte concentrations. Differential counting of peripheral blood cells revealed significant granulocytosis, whereas the fraction of circulating lymphocytes was decreased. Microscopic examination and cell cycle analyses of rat bone marrow revealed stimulated hematopoiesis. An increase in the plasma concentration of corticosterone was observed in the middle of the experimental period, but was similar in the two groups by the end of the period. The reduced PMNL phagocytic capacity observed following repeated hypobaric hypoxia may have consequences for host defence in situations of exposure to hypoxia.

INTRODUCTION

Following rapid ascent to altitudes above 3.000 m many people experience severe headache, nausea, dizziness, breathlessness, and general weakness. These symptoms are collectively designated as "acute mountain sickness" (Sutton, 1971; Rizzi, 1989; Houston, 1992), and it is generally held that the main underlying cause is the hypoxia rather than the hypobaria (Dickinson, 1983). The physiological responses to acute hypoxia include alterations of water-salt balance (Frayser et al., 1975), hormone concentrations (Sutton et al., 1977; Frayser et al. ,1975), coagulation (Maher et al., 1976; Chohan 1984), hematopoiesis (Siri et al., 1966; Mirand et al., 1957; Reddy et al., 1986). Further, exposure of animal to simulated high altitude induces alterations of their immune system, which seem to influence their host defence (Altland et al., 1963; Berry et al., 1953; Erlich et al., 1962; Highman, 1950).

The phagocytic cells form the first line of defence against invading micro organisms (Klebanoff et al., 1978). Both polymorphonuclear neutrophilic granulocytes (PMNL) and mononuclear phagocytes have microbicidal systems which depend upon sufficient oxygen supply in the tissues to function adequately (Klebanoff et al., 1978). It is shown that *in vitro* exposure of human neutrophils to anaerobic conditions significantly reduce their killing capacity (Mandell, 1974). Acute exposure of mammals to hypobaric hypoxia induces leukocytosis (Coates et al., 1983; Reddy et al., 1986; Siri et al., 1966), but the exact mechanism remains unclear. There are also reports stating

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that exposure to hypobar hypoxia has no influence on the peripheral concentration of leukocytes (Ward, 1989). Further, little is known about the possible effects of *in vivo* exposure to acute hypoxia on phagocyte function. Leukopoiesis is also demonstrated by exposing the organism to various types of psychological and physiological stress (Schaefer et al., 1987; Rai et al., 1981; Gray 1987).

The present study was undertaken to determine the effect of repeated hypobaric hypoxia on the number and function of circulating neutrophilic granulocytes in rats.

MATERIALS AND METHODS

Animals

Male Wistar rats (Møllegaard Breeding Centre Ltd., Denmark), weighing 200-250 g at the onset of the experiment, were used. The animals were given food and water *ad libitum*, and kept in the animals quarters for 12 days before the experiments started. The animals were treated according to a standard protocol approved by the local ethics committee.

Decompression

Hypobaric chambers: The experiments were conducted in four aluminium chambers with glass windows. Two chambers, used to expose the animals to hypobaric conditions, were evacuated by vacuum pumps. The flow of air through the chambers was sufficient to provide at least five complete volume changes per hour. The remaining two chambers were kept at normobaric conditions at all times, and used by the control animals. All four chambers were placed in the same room and both groups were exposed to the same amount of cage handling, noise, etc., the only difference being the hypoxia exposure. The temperature in all chambers was kept at 26 °C and the relative humidity at 70%.

Protocol: Groups of rats were exposed to repeated hypobaric hypoxia for 0-7 days. Each day the animals were exposed to 0,5 atm (5.500 m) for 17 hours, followed by 7 hours at 1 atm (sea level). The rats exposed to hypoxia consumed less water and food than the control animals during the first 2-3 days of the experimental period. However, after an initial loss of weight, they increased their food and water intake, and gained weight at about the same rate as the control animals.

Each day of the experimental period 10 rats from each experimental group were anesthesized (phenobarbital and midazolam) and blood drawn by heart puncture into Vacutainers containing EDTA or heparin. The animals were then scarified. Ten animals from both the control group and the hypoxia group were kept at 1 atm. for 10 days after the experimental period to get an estimate of the duration of possible changes induced by the hypoxia exposure.

Haematological parameters

Peripheral blood: Total leukocyte and platelet counts were obtained by microscopy and corrected for changes of hematocrit. Hematocrit values were determined by centrifugation (Hemofuge, Heraus Christ, FRG), whereas haemoglobin concentration was determined spectrophotometrically (Hitachi Spectrophotometer, model 100-400, Japan). Leukocyte differential counts were obtained by microscopial examinations of Diff-Quick (Mertz+ Dade AG, Switzerland) stained smears.

Bone marrow: Bone marrow cells were obtained by flushing one femur per animal with 2 ml of phosphate buffered saline (PBS). The cells were washed once in 5 ml of PBS. Then half the pelleted cells were resuspended in 1 ml PBS and fixed by adding 5 ml ice-cold acetone. The

remaining cells were resuspended in 0,2 ml pooled rat serum and smears were made. The smears were stained with Diff-Quick, blinded and analysed by light microscopy.

PMNL functions

Phagocytosis: Phagocytosis was determined by a modification of the method described by Bjerknes at al. 1983. Briefly, peripheral blood leukocytes were prepared by lysing the erythrocytes by adding 1 ml of heparinized peripheral blood to 8 ml of a lysing solution (8.0 g/l Na HCO_3 and 3.3 g/l EDTA). The cells were then washed once in PBS, resuspended in Hank's balanced saline solution (HBSS) (Flow Laboratories, UK) containing 0.5 % bovine serum albumin (Sigma Chemicals, USA), and counted by microscopy. After differential counting of Diff-Quick stained smears, the PMNL concentrations were adjusted to 5 x 105/ml. Ethanol killed *Staphylococcus aurus* (Oxford strain 209) were labelled with fluorescein-isothiocyanate (FITC) (Sigma Chemicals, USA), suspended in HBSS and counted by flow cytometry as described earlier (Bjerknes et al.., 1983). For the incubation, 2.5 x 105 PMNLs were mixed with 5 x 106 bacteria in the absence or presence of 10% pooled rat serum for 0-20 minutes at 37 degrees C. The phagocytosis was terminated by adding 3 ml ice-cold PBS containing 0.1 % paraformaldehyde to each tube. The fixed samples were kept in a refrigerator (4 °C) until analysed by flow cytometry (see below).

Opsonins

In order to examine the phagocytic capacity in the presence of heat sabile opsonins, (mainly immunoglobulins) only, pooled rat serum that had been to 56 °C for 30 minutes (to inactivate complement factors) was used.

Flow cytometry

An Ortho Cytofluorograf 50H, interfaced to a Model 2150 Computer, was used. The wavelenght excitation light was 488 nm. FITC-fluorescence was measured at 515-575 nm, whereas wide and forward angle light scatter were measured at 488 nm.

Phagocytosis: Free extra cellular bacteria, non-phagocytes and phagocytes were discriminated and quantified by combined flow cytometric measurements of FITC-fluorescence and forward angle light scatter as described by Bjerknes et al., 1983. The mean number of bacteria per phagocyte equalled the difference between the initial and the final numbers of free extra cellular bacteria divided by the number of phagocytosing PMNLs (Bjerknes et al., 1983).

Phagocyte size and granularity: Forward angle light scatter measurements were used to obtain estimates of cell size, and estimates of cell granularity were obtained from measurements of wide angle light scatter (Loken et al., 1982; Sklar et al., 1984). Changes of phagocyte size and granularity were given as changes of the mean channel number of forward and wide angle light scatter, respectively.

Bone marrow and cell cycle analyses: Fixed bone marrow cells (see above) were washed once in PBS and incubated with RNAse (0.1 mg/ml) (Sigma Chemicals, USA) for 10 minutes at 37 °C, before their DNA was stained with propidium iodine (PI) (Sigma Chemicals, USA) (0.1 mg/ml in PBS) (Lund-Johansen et al., 1990). The single cell DNA content was determined by a standard flow cytometric method (Melamed et al., 1979) and the cell cycle analyses performed by the Model 2150 Computer. The fractions of cells in the G0/G1, S and G2/M phases of the cell cycle were determined.

Corticosterone

Plasma was collected from each animal and stored at -70 °C. The corticosterone concentrations were determined for all samples in parallel using a commercially available radio immunoassay kit (Corticosterone (125), Cambridge Medical Technology Co., USA).

Statistical method

Significances of difference were determined by Student´s *t*-test.

RESULTS

Haematology

The hematocrit values increased during the period of hypoxia exposure, and at day 7 the value was 0.54. Ten days following the exposure to hypoxia, the hematocrit fractions were similar in the two groups (Figure 1).

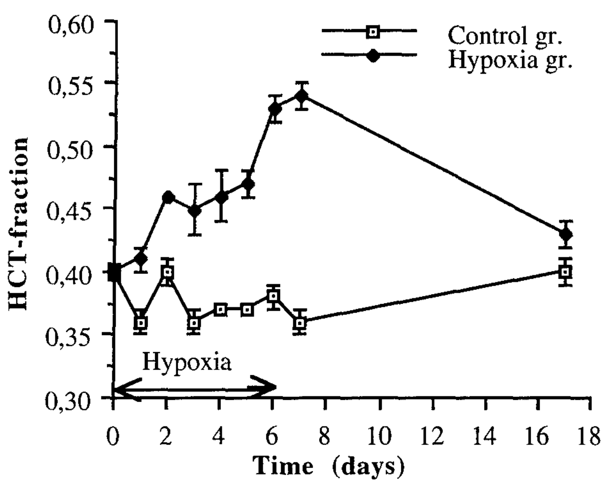

Figure 1: Hematocrit fraction in rats exposed to repeated hypobaric hypoxia vs. controls. Results given as mean ± SEM; n=1

The haemoglobin concentration increased likewise, with a peak value at day 7 (15.6 g/dl). Ten days after the termination of the hypoxia exposure the haemoglobin concentration was still significantly higher in the hypoxia group (Fig. 2).

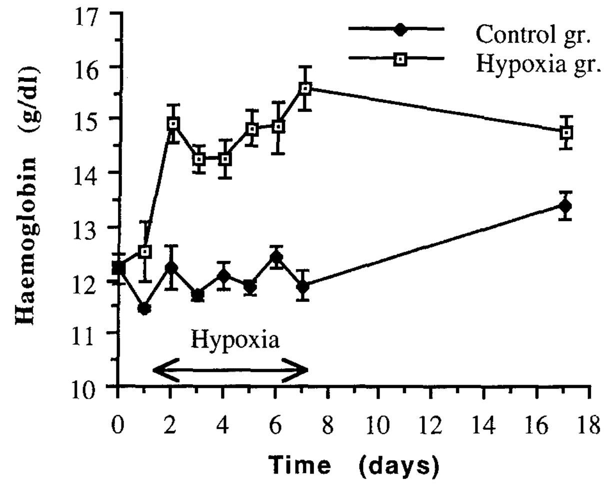

Figure 2: Haemoglobin concentration in rates exposed to repeated hypobaric hypoxia vs controls. Results given as mean ± SEM; n=10

The platelet concentration was 24% in the hypoxia group than in the control group on day 2, and on day 7 the difference between the two groups was 47%. Ten days after the hypoxia exposure the platelet concentration was still significantly higher in the hypoxia group.

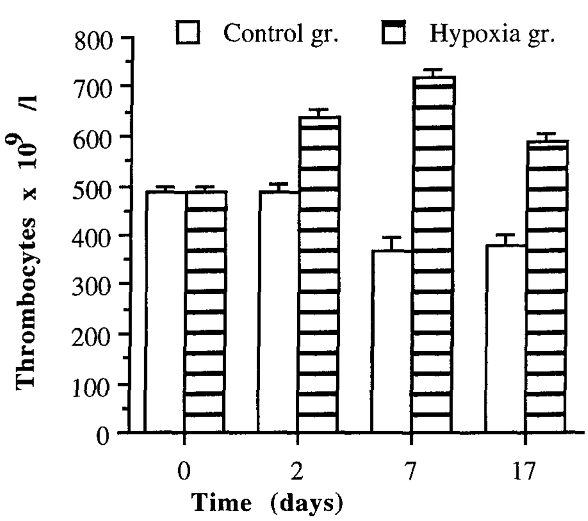

Figure 3: Peripheral thrombocyte concentration in rats exposed to repeated hypobaric hypoxia vs. controls. Results given as mean ± SEM; n=10

Repeated hypobaric hypoxia induced an increase of the peripheral leukocyte concentrations. The concentration increased steadily, day by day during the hypoxia period, with a peak value on

day 7. On day 17 the leukocyte concentrations in the two groups were similar (Fig. 4).

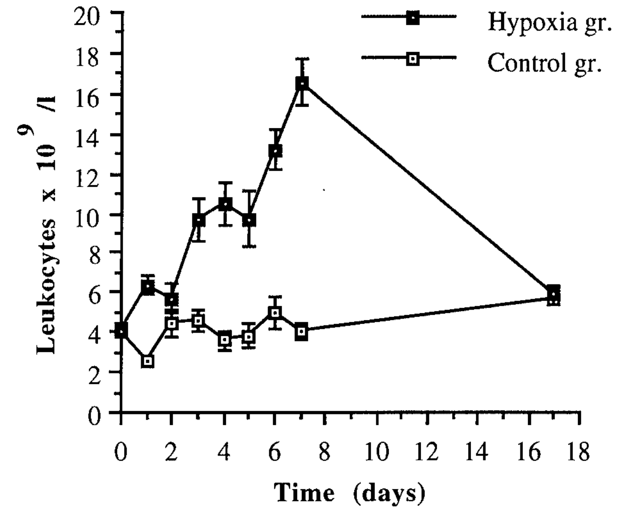

Figure 4: Peripheral leukocyte concentration in rates exposed to repeated hypobaric hypoxia vs controls. Results given as mean ± SEM; n=10

Differential counts of peripheral blood revealed granulocytosis during the hypoxia period. The values varied considerably during the experimental period, with a peak value on day 4. The percentage of lymphocytes decreased, whereas the fraction of monocytes remained unaltered. Ten days following the hypoxia period, the differential counts in the two groups were identical. (Fig. 5). There was no significant left shift of the granulocytes following exposure to hypoxia (results not shown).

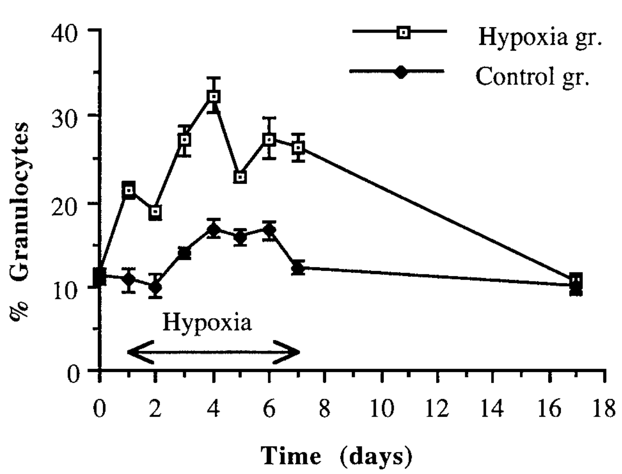

Figure 5: Percentage of peripheral neutrophilic granulocytes in rats exposed to repeated hypobaric hypoxia vs controls. Results given as mean ± SEM; n=10

Semiquantitative microscopic examinations of bone marrow smears revealed both increased erythropoiesis and leukopoiesis following hypoxia (results not shown). Flow cytometric cell cycle analyses demonstrated that the fraction of bone marrow cells in S-phase was increased by 20% (19.4 ± 5.3) and by 42% (22.9 ± 5.7; $p<0.05$) following 2 and 7 days of hypoxia respectively, from day 0 (16.9 ± 6.6). Ten days after termination of the hypoxia exposure the fraction of S-phase cells was increased by 36% (21.9 ± 6.1; $p<0.05$) compared to the control animals (16.1 ± 5.4) (Fig. 6)

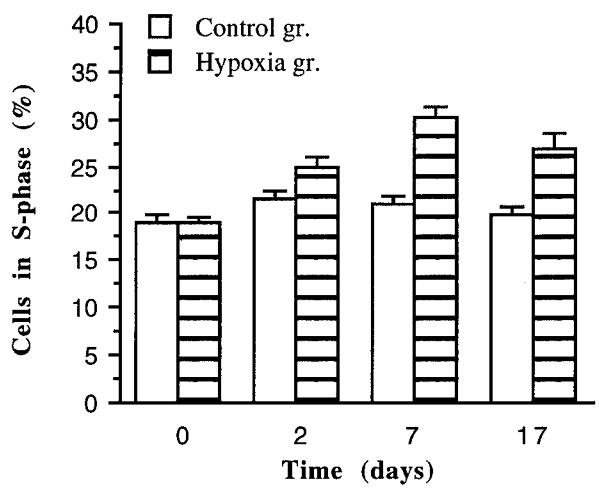

Figure 6: Percentage of bone marrow cells in S-phase in rats exposed to repeated hypobaric hypoxia vs controls. Results given as mean ± SEM; n=10

Phagocyte functions

Phagocytosis: Exposure of rats to hypobaric hypoxia induced a reduction of their PMNL opsonin mediated phagocytosis. The percentage of phagocytosing PMNLs was not altered, but the number of bacteria ingested per phagocyte was significantly decreased, both in the presence of normal and heated pooled rat serum. Ten days

following termination of the hypoxia exposure, the PMNL phagocytic capacity was similar to that of the controls (Table 1, Fig. 7). In the absence of serum, the number of bacteria per phagocyte were slightly reduced following exposure to hypoxia (Table 1). Serum obtained from rats exposed to hypoxia did not influence the phagocytic capacity of normal PMNLs (results not shown).

	Opsonin		
Situation	No PRS	Heated PRS	Normal PRS
Pre-Hypoxia	3.1 ± 0.5	9.3 ± 0.4	14.1 ± 1.1
Hypoxia Day 2	2.5 ± 0.4	6.0 ± 0.5 **	9.7 ± 0.8 *
Hypoxia Day 7	1.9 ± 0.6 *	4.5 ± 0.8 **	7.6 ± 1.1 **
Post-Hypoxia	2.7 ± 0.2	8.8 ± 0.9	14.4 ± 0.7

Table 1: The phagocytic capacity of PMNLs from rats exposed to repeated hypobaric hypoxia vs controls. Results given as mean number of bacteria ingested per PMNL ± SEM; n=10

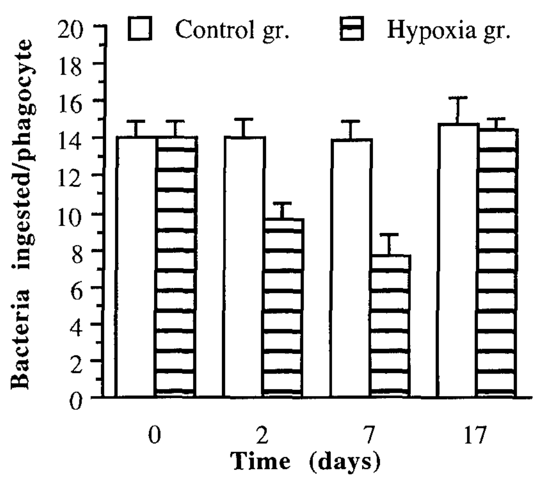

Figure 7: Number of bacteria ingested per phagocyte in rats exposed to repeated hypobaric hypoxia vs controls. Results given as mean ± SEM; n=10

Phagocyte size and granularity: Exposure of rats to repeated hypobaric hypoxia influenced neither the size nor the granularity of phagocytosing PMNLs as evaluated by single cell forward angle or wide angle light scatter measurements (results not shown).

Corticosterone:
There was an initial increase in the plasma corticosterone concentration in both the experimental group and in the control group on day 1 compared to day 0. The corticosteron concentration varied considerably throughout the experimental period, on days 2,3, and 6 the concentration was significantly higher in the hypoxia groups than in the control groups. No significant increase of the corticosterone concentration could be demonstrated neither on day 7, nor on day 17 (10 days after termination of the hypoxia exposure) (Fig. 8).

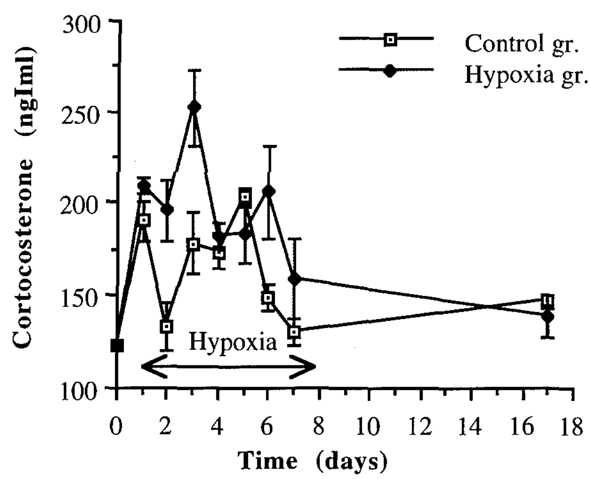

Figure 8: Plasma corticosterone concentration in rats exposed to repeated hypobaric hypoxia vs controls. Results given as mean ± SEM; n=10

DISCUSSION

The present investigation demonstrates that repeated hypobaric hypoxia (17 hours at 0.5 atm daily for 7 consecutive days) results in an increase of hematopoietic activity and a reduction of

peripheral blood PMNL phagocytic capacity in rats. The increase in haemoglobin and hematocrit concentrations is a result of the reduced oxygen tension in the animals environment. The reason for the increased platelet concentration is not clear, but it could be due to the generally stimulated erythropoietic activity since erythropoietin, which is the main trigger for increased red blood cell production, also stimulates differentiation of megacaryocytes. The leukocyte concentration increased during the hypoxia exposure, and in particular the fraction of neutrophil granulocytes. This could be due to stimulation of several hematopoietic growth factors, which again leads to increased differentiation of stem cells and precursor cells. If the bone marrow is stimulated in this manner, the reservoir of immature precursor cells will be reduced, and the rate of stem cell differentiation will increase.

Phagocyte functions may be influenced by exposure to hypoxia *in vitro* (Gillespie et al., 1987; Lingaas et al., 1987; Mandell, 1974). Low oxygen tension provoke sequestration of PMNLs in isolated rabbit hearts (Gillespie et al., 1987). In addition, the PMNL microbicidal capacity is significantly reduced at anaerobic conditions in vitro (Mandell, 1974). This has been attributed to impairment of PMNL killing mechanisms dependent on oxygen (Mandell, 1974). Furthermore, a slight reduction of phagocytosis has been observed for human PMNLs exposed to hypobaric hypoxia (0.4 atm for 6 minutes) (Lingaas et al., 1987). Our study demonstrated that the uptake of bacteria by PMNLs from animals exposed to repeated hypobaric hypoxia was reduced. Thus, alteration of oxygen tension may influence both PMNL adhesion, phagocytosis and intracellular killing. However, the mechanisms by which this occurs remains to be determined.

The present investigation demonstrated significant reduction of PMNL opsonin dependent phagocytosis of *S. aurus*, whereas the PMNL opsonin independent phagocytosis was only slightly reduced. Thus, it is possible that the hypoxia exposure influenced PMNL opsonin receptor function.

Glucocorticoids are known to influence PMNL adherence, whereas PMNL chemotaxis, phagocytosis and intracellular killing are inhibited only at very high concentrations of glucocorticoids probably not attainable *in vivo* (Parillo et al., 1979). Hence, Baardsen, 1976, reported that the phagocytosis by rat PMNLs *in vitro* were only inhibited at concentration of hydrocortisone of 1 mg/dl or higher. The maximal concentration of corticosterone observed following hypoxia in our experiment was 250 ng/ml, suggesting that the reduced PMNL phagocytic capacity was not due to increased concentration of corticosterone.

A significant peripheral blood leukocytosis was observed in this study. Differential counts revealed significant granulocytosis, whereas the fraction of lymphocytes decreased. Microscopic examinations and cell cycle analyses of rat bone marrow showed stimulated hematopoiesis.

Administration of glucocorticoids is followed by lymphopenia in both rats (Claman, 1972) and humans (Parillo et al., 1979). In man, glucocorticoids also induce peripheral granulocytosis by increasing the release of granulocytes from bone marrow, as well as increasing the circulating half-life of granulocytes and reducing their egress from the blood (Parillo et al., 1979). In our experiments a slight, but significant, increase of corticosterone concentrations were demonstrated following 2,3 and 6 days of hypoxia exposure, whereas after 7 days the increase was no longer significant. The

granulocytosis persisted even at day 7 of hypoxia exposure. Thus, it is possible that the granulocytosis observed presents a combined effect of hypoxia and increased corticosterone concentration.

In conclusion, significant granulocytosis and reduced granulocyte function was observed in this study. The increase in granulocyte concentration does not make up for the reduced phagocytic capacity, and this might have consequences for host defence in situations of hypoxia.

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IS THE SLOWING PRODUCED BY HYPOXIA PERIPHERAL OR CENTRAL IN ORIGIN?

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SUMMARY

Since the pioneering work of Ross McFarland, it has been an article of faith in textbooks and reviews of the literature that hypoxia disrupts a variety of central cognitive mechanisms. However, a series of studies undertaken in our laboratory challenges this traditional view. These studies suggest that the slowing of information processing, which is manifested as an increase in reaction time (RT), may be specific to peripheral perceptual mechanisms. Our approach has been to stabilize SaO_2 at 65% using highly trained subjects, and then to employ the Additive Factors Method (AFM). The AFM allows the locus of slowing to be isolated to one or more of the information processing stages comprising the RT process. A systematic investigation of perceptual and central stages in the visual modality has revealed that only the earliest preprocessing stage is directly affected by hypoxia. These results implicate the visual system in slowing, and raise the question of whether slowing is specific to vision. We addressed this question by bypassing the visual modality and using a kinaesthetic weight discrimination task. In this AFM experiment, the vocal discrimination RT of hypoxic blindfolded subjects to pairs of lifted weights was measured. The surprising result was that, in contrast to all of the preceding visual experiments, hypoxia did not increase RT. This experiment provides convergent evidence that central stages of processing are unaffected by hypoxia, and that slowing is specific to the visual system. How can the widespread behavioral effects of hypoxia be explained if central stages are unaffected? One possibility is that early slowing exerts a profound effect on the system as a whole by acting as a bottleneck to later processing.

INTRODUCTION

Ross McFarland pioneered the study of hypoxia on perceptual and cognitive functioning in the 1930s and 40s, and he left us with a two-fold legacy. First, he performed a series of definitive studies showing the extreme sensitivity of visual functioning to hypoxia (1-3). Second, he made the assumption in a number of review papers that cognitive functions are globally impaired by hypoxia (4-6). This assumption seemed perfectly reasonable for two reasons: severe hypoxia presumably affects all parts of the brain, and virtually any cognitive or perceptual-motor task shows impairment under hypoxia. The belief in global impairment has become well entrenched in textbooks and reviews of the literature, and is usually expressed by statements that abilities such as short-term memory, conceptual reasoning and pattern recognition are impaired, and that complex reaction time (RT) is more sensitive than simple RT (7-11).

A major difficulty faced by early investigators was the absence of theoretical models that could be applied to the problem of understanding the manner in which hypoxia disrupts cognition. This problem was recognized some time ago (12), and Ledwith (13) was one of the first investigators to frame questions about the cognitive effects of hypoxia in terms of a theoretical model - the information processing model of human performance (14).

The series of experiments reviewed in this paper are in the tradition of the information processing model, since they are based on Sternberg's Additive Factors Method (AFM) (15-17). The power of this approach lies in its ability to break RT into components - called stages in the model. Since it is well known that hypoxia slows RT (18), the AFM can be used to address the question of which stages comprising the RT process are slowed by hypoxia. In these terms, the strong form of the global impairment hypothesis is that all components are slowed. A weaker form is that most components are slowed. Surprisingly, neither the strong nor the weak forms of the global impairment hypothesis are supported by our data. Rather, it appears that slowing may be localized to only one or two components. We shall call the strong form of the latter point of view the single locus hypothesis. The strong forms of both the global impairment and single locus hypotheses are illustrated in Figure 1. The advantage of thinking in terms of the extreme form of each point of view is that the research question is sharpened and alternative hypotheses can be eliminated in a systematic manner.

THE ADDITIVE FACTORS METHOD

The AFM is based on the assumption that information processing proceeds serially through stages. Approximately seven stages involving stimulus (perceptual), central and response (motor) processing have been identified (Figure 2). Stages are identified by manipulating the difficulty of two task factors and measuring their influence on RT. A task factor is an experimental variable that influences a stage. For example, stimulus intensity is manipulated to influence the preprocessing stage. An additive effect between two task variables indicates that the variables are influencing different stages, whereas an interactive effect indicates that they are influencing the same stage. The AFM has been used to investigate a variety of stressors (19,20). In these circumstances, a task factor representing the stage under investigation is manipulated factorially with the stressor. Three possible outcomes are illustrated in Figure 3. An interaction indicates a direct slowing of the stage by the stressor. Additivity indicates that stage(s) other than the one currently under direct investigation are slowed. The third outcome would not normally occur, since it indicates that the stressor does not slow RT in the first place. Using this approach, we have systematically investigated all perceptual and central stages in order to uncover the pattern of slowing produced by hypoxia.

INDUCTION OF HYPOXIA

We induce a relatively severe level of hypoxia with low oxygen mixtures that are adjusted to produce an arterial oxyhemoglobin

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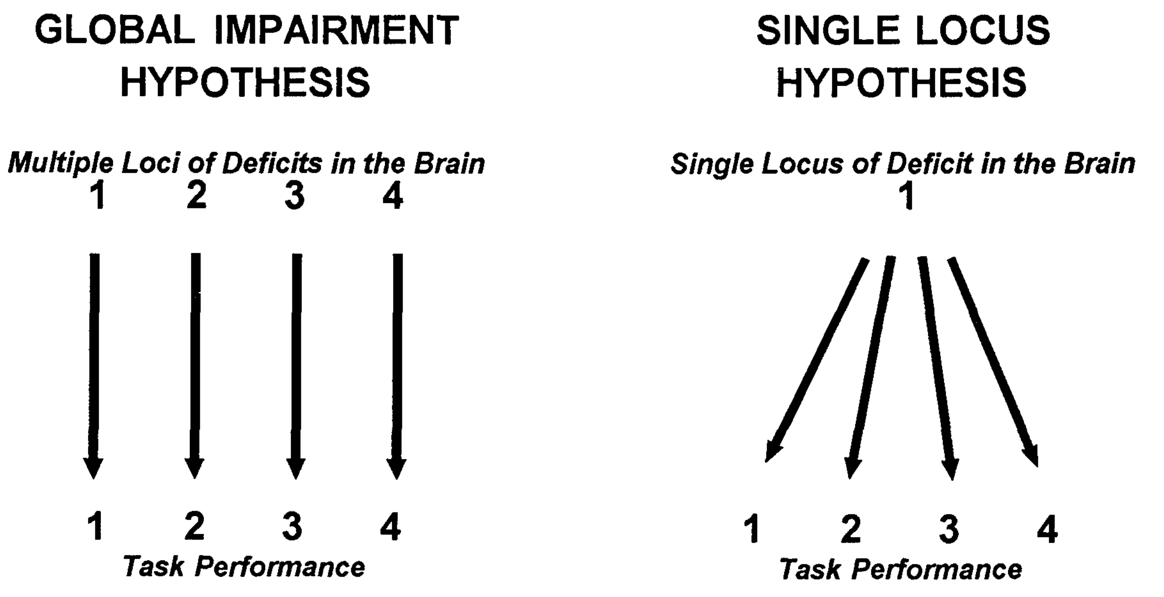

Figure 1. Two hypotheses that explain the effects of hypoxia on task performance.

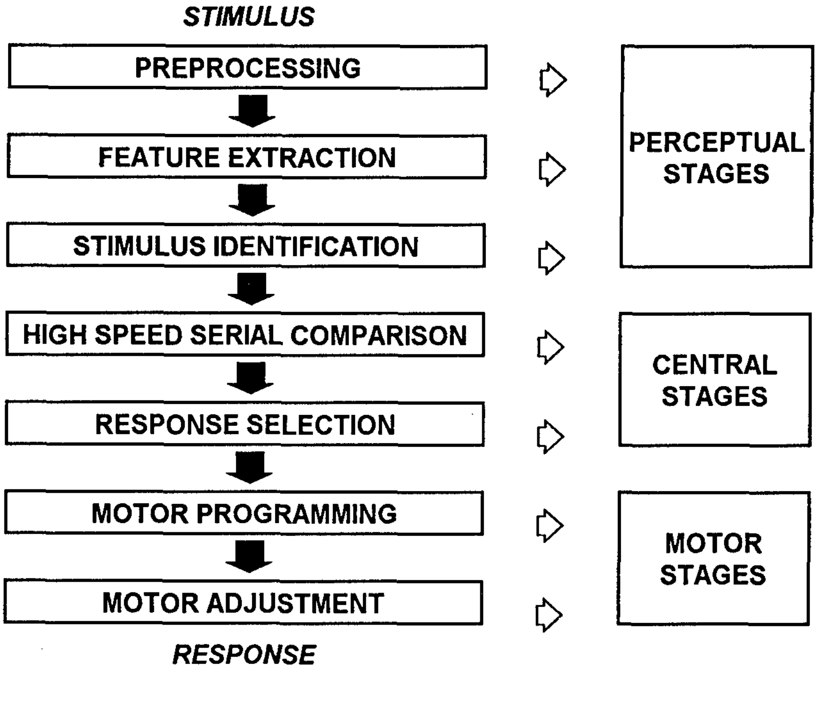

Figure 2. The linear stage model assumed by the Additive Factors Method.

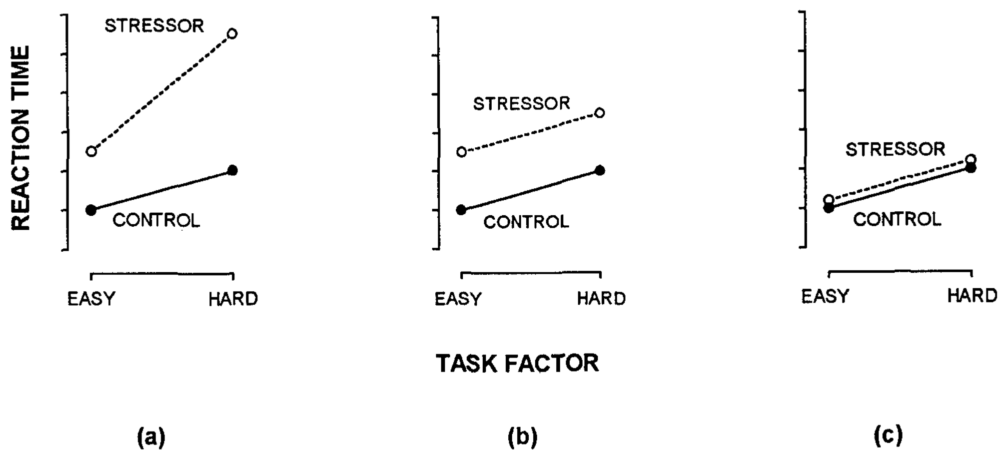

Figure 3. Additive Factors Method outcomes.

saturation (SaO_2) of approximately 65%. This is achieved by linking high-pressure bottles that vary in O_2 content to a common valve. After suitable pressure reduction, the subject breathes the mixture through an aviation type oro-nasal mask. An ear or finger oximeter is used to monitor SaO_2, and an experimenter maintains the desired SaO_2 level by selecting the appropriate bottle via the common valve. A skilled experimenter can usually hold SaO_2 to within ± 2% of the desired value. To achieve this degree of control, however, the subjects must be trained to inhibit their natural desire to hyperventilate. Without this precaution, marked fluctuations in SaO_2 are the rule. A consequence of controlling breathing is that the arterial partial pressure of carbon dioxide remains within normal values (21). An SaO_2 level of 65% is usually achieved over a 10-15 min period, and the subjects remain at this level for up to 20 min. This degree of hypoxia is tolerated quite well. Some discomfort is felt, and lightheadedness, paraesthesia and headache may be reported, but there is no disorientation, and the subjects can follow instructions without difficulty. Controlling SaO_2, rather than controlling altitude in a hypobaric chamber, or the O_2% of the breathing mixture, eliminates an important source of variability in hypoxia experimentation - between subject differences in SaO_2 level (8).

PROCEDURES

We employ a repeated measures design exclusively, since it is not feasible in terms of either time or cost to use a between-subject design in which one group of subjects breathes air as a control, and the other group breathes the low O_2 mixture. It has been argued that repeated measures designs involving stressors can be subject to unwanted asymmetrical transfer effects (22), but we avoid this problem by thoroughly training the subjects on the task under both normoxia and hypoxia. Training eliminates the anxiety that is likely to surround exposure to a stressor such as hypoxia, as well as the distracting influence of the subjective symptomatology - both important sources of variability. In addition, the subjects are trained to maintain a constant level of task accuracy, since this is an assumption of the AFM, and the error rate of untrained subjects typically increases under hypoxia (23). Thorough training decreases the variability of performance, thereby increasing the sensitivity of the experiment, and allowing more efficient and powerful experiments to be run. This is important when the aim of these experiments is to distinguish between an additive and an interactive effect.

AFM EVIDENCE FOR THE SINGLE LOCUS HYPOTHESIS

The first clue that hypoxia does not influence all central cognitive mechanisms came from a non-AFM experiment that was designed to tease apart the effects of hypoxia on complex perceptual motor performance (21). One element of this task involved variation in the number of choices to be made by the subject. When number of choices was plotted against response time, additive slowing due to hypoxia was observed. A second element involved variation in stimulus luminance, and in this case interactive slowing was observed.

The surprising inference from the aforementioned experiment, that task complexity in terms of number of choices is insensitive to hypoxia, was tested directly by varying the number of choices and measuring RT rather than response time (24). Once again, an additive effect was found. In the original paper this result was interpreted in terms of the Hick-Hyman function (14), but it can also be interpreted in terms of AFM logic as indicating that the response selection stage is not slowed by hypoxia (16).

Another central stage that we have investigated is high speed memory scanning (25). This task involves short-term memory (15), and is of particular interest because of the wide-spread belief that this function is impaired by hypoxia (6-9,11,12). The subjects were presented with memory sets of 2, 4 or 6 digits, followed by a test digit. The task was to decide whether the test digit had been included in the memory set or not. The results of this experiment are illustrated in Figure 4, and a statistical analysis of these data

revealed an additive rather than an interactive effect. The conclusion from these results was that this aspect of short-term memory is unaffected by hypoxia.

The stimulus identification stage was initially investigated with a line-length discrimination task (26). In this task, the difference in length between two lines was manipulated, and the subject decided which member of the pair was longer. Under these circumstances, RT is a linear function of Crossman's confusion function (27):

$$RT = (\log_2 x_1 - \log_2 x_2)^{-1}$$

where x_1 = length of longer line, and x_2 = length of shorter line. We found a small but significant interaction between stimulus discriminability and hypoxia, suggesting that the stimulus identification stage is slowed by hypoxia. However, there was also evidence that AFM assumptions were violated in this experiment, and we speculated that the degradation in visual acuity caused by hypoxia (5) made discrimination between the lines progressively more difficult as the difference between them decreased.

To test this hypothesis, we conducted an experiment using a mental rotation task that also probes the stimulus identification stage (16), but which we assumed would be relatively insensitive to a degradation in visual acuity (28). In this task, two relatively simple shapes were presented simultaneously to the subject. The right hand shape was either identical to, or a mirror image of, the left hand shape. The right hand shape was also rotated in the picture plane through an angle of 0°, 60°, 120° or 180° relative to the left hand shape. The task of the subject was to decide whether the shapes were identical or different. Under these circumstances, RT is a linear function of the angular difference between the shapes (29). The results of this experiment are illustrated in Figure 5. They are quite clear cut. The slowing typical of hypoxia is evident, but it is additive rather than interactive.

This mental rotation experiment is also of interest in relation to the mannikin test which was invented to probe the ability of pilots to orient themselves with respect to an external visual environment (30), and which has been used as a sensitive test of hypoxia (31). Presumably, mental rotation plays an important role in this task, since the subject must distinguish between the left and right hands of a mannikin figure that is rotated in both the picture and depth planes. It now seems clear that the impairment produced by hypoxia on this task cannot be due to impairment of the 'complex' process of mental rotation.

The effects of stressors on feature extraction have been extensively investigated in the AFM literature (19), but it is only very recently that we have investigated the effects of hypoxia on this stage (32). Feature extraction is probed by degrading the quality of the stimulus. In our case subjects discriminated between male and female names that were obscured by a random dot pattern (20). As with all the preceding stages that we have investigated, a clear-cut additive effect emerged from this experiment (Figure 6).

It will be recalled that a relatively complex perceptual-motor task provided the first clue that vision plays an important role in the slowing produced by severe hypoxia (21). It has also been established that vision plays a role at mild levels of hypoxia. The task referred to above was also used in an experiment designed to pinpoint the SaO_2 threshold for slowing, and the slope of the threshold function was found to be inversely related to stimulus luminance (33). These experiments focussed attention on the preprocessing stage - the first perceptual stage that carries out

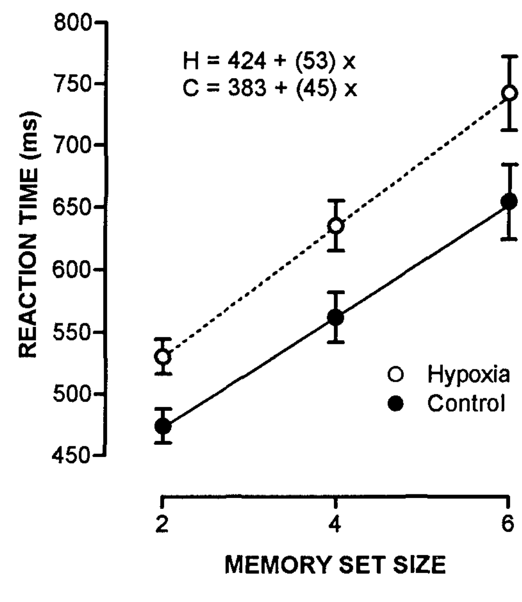

Figure 4. Reaction time as a function of memory set size and breathing mixture. *(Reprinted with permission from Aviation, Space and Environmental Medicine.)*

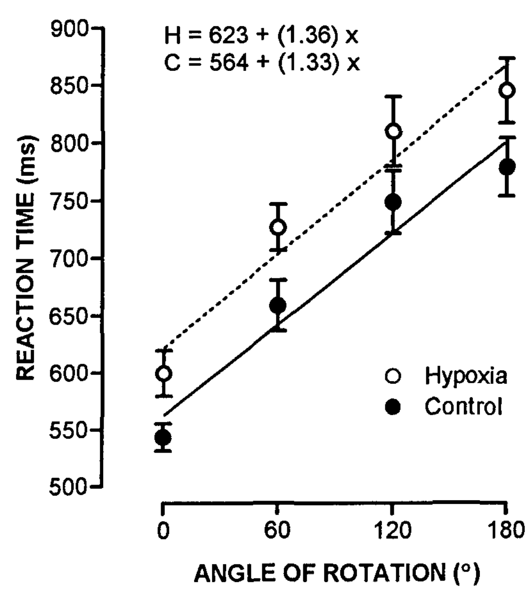

Figure 5. Reaction time as a function of angle of rotation and breathing mixture. *(Reprinted with permission from Ergonomics.)*

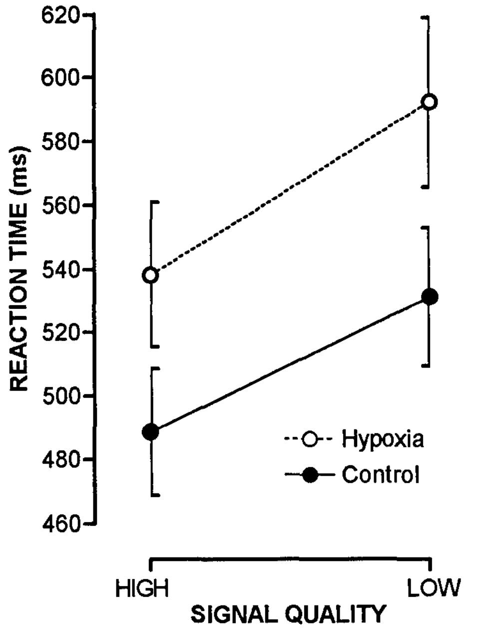

Figure 6. Reaction time as a function of stimulus quality and breathing mixture.

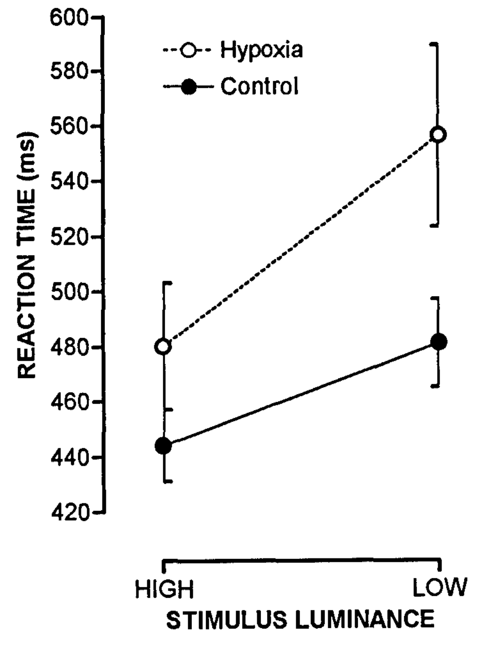

Figure 7. Reaction time as a function of stimulus luminance and breathing mixture. *(Reprinted with permission from Aviation, Space and Environmental Medicine.)*

primitive transformations on the stimulus, and which is sensitive to manipulations involving stimulus intensity and contrast (16). We investigated this stage by asking the subject to discriminate between male and female names that varied in luminance (34). In contrast to the additive effect found with every other stage that follows preprocessing, a clear-cut interaction emerged from this experiment (Figure 7). This result has now been replicated in two further experiments, one of which used different stimuli from the names employed in the first experiment (26,32). Thus it appears that the preprocessing stage is the sole contributor to the slowing produced by hypoxia.

The experiments described above share a common feature - they were all conducted in the visual modality. Indeed, virtually all experiments in the hypoxia literature that have measured complex performance, or speed of responding with simple tasks, have employed vision. The argument in support of the role of vision in slowing would be greatly strengthened if convergent evidence could be brought to bear on the issue by demonstrating an *absence* of slowing when vision is eliminated as the input modality.

We therefore conducted an experiment with this idea in mind (35). In this experiment, the stimulus identification stage was investigated with a kinaesthetic analogue of the visual line length discrimination task discussed above (26). Thus the data could be plotted in terms of Crossman's confusion function (27). To our knowledge, the effects of hypoxia on the kinaesthetic modality have not been investigated previously. The subjects (N=12) were blindfolded, and their task was to lift two canisters simultaneously and decide which one was heavier. Decision time was recorded by a millisecond timer using a voice actuated microphone in the oro-nasal mask. Task difficulty was manipulated by varying the

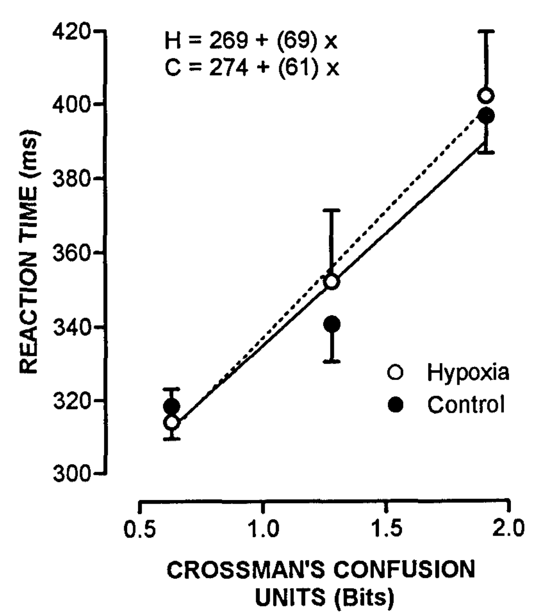

Figure 8. Reaction time as a function of stimulus discriminability and breathing mixture in a weight discrimination task.

difference in weight between the canisters. The results of this experiment are illustrated in Figure 8. As expected, RT increased as a function of task difficulty, but the striking feature of these data is that hypoxia did *not* slow responding. This is striking because slowing has been observed in all thirteen previous hypoxia experiments from our laboratory involving vision - providing SaO_2 was above the threshold for slowing. These results cannot be explained by a lack of severity in the degree of hypoxia that was imposed, since mean SaO_2 was calculated to be 65%. The possibility that the weight discrimination task was too insensitive to detect slowing, either because it is generally insensitive to stressors, or because some aspect of the experiment was flawed, can also be ruled out because we have employed this task previously to demonstrate slowing due to nitrous oxide (36).

DISCUSSION

Taken together, these experiments lead to several conclusions. First, those aspects of the kinaesthetic modality involved in the weight discrimination task are very insensitive to hypoxia. Second, given that kinaesthesis is insensitive to hypoxia, an absence of slowing in the weight discrimination experiment is consistent with the conclusion from the visual experiments that slowing is restricted to the preprocessing stage, and therefore presumably involves vision. The conclusion that vision plays an important role in slowing is consistent with the well known sensitivity of this modality to hypoxia (5). In this regard, at least one direct link can be inferred between the disruption of vision and the speed of processing - the inverse relationship between RT and stimulus luminance, since the latter is effectively decreased by hypoxia (5). This relationship is illustrated in Figure 9. The effective decrease in luminance due to hypoxia is shown as a shift to the right of the RT function. The effect of this shift on RT at two levels of stimulus luminance is illustrated by the open circles, while the normoxic RT levels are represented by closed circles. The shift produces a greater amount of slowing at the low level than at the high level of luminance, thereby explaining the interaction observed in AFM experiments (e.g., 34).

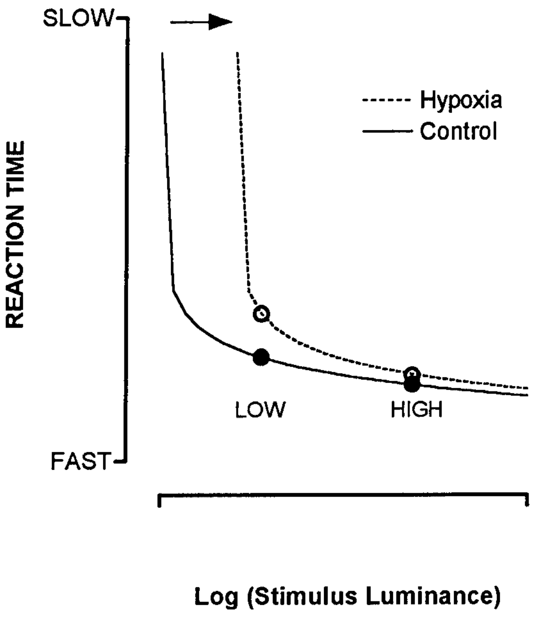

Figure 9. Relationship betweem stimulus luminance and reaction time. *(Adapted from Teichner W, Krebs M. Laws of the simple visual reaction time. Psychological Review 1972; 79:344-358.)* Hypoxia shifts the function to the right, thereby causing more slowing at the low level than at the high level of stimulus luminance. See text for details.

The foregoing explanation does not preclude other sources of slowing arising from defective vision, such as blurring of the stimulus due to a loss of acuity. Third, a corollary to the conclusion that slowing is restricted to vision is that later cognitive stages are not slowed. This of, course, is contrary to the traditional view that hypoxia disrupts a variety of cognitive mechanisms.

The argument outlined above raises a number of issues. The first is that we have not mentioned the motor stages of motor programming and motor adjustment (Figure 2). These stages have not been investigated directly using the AFM approach because there is reason to believe from another line of evidence that they are not slowed directly. It is beyond the scope of the present paper to discuss this evidence in detail, but it is based on a series of experiments demonstrating that RT and the latency of the event-related brain potential P300 are slowed to the same extent by hypoxia (34,37-39). The fact that P300 latency indexes hypoxia in concert with RT implies that slowing is largely stimulus-related, since there is a good deal of evidence that P300 latency is sensitive to stimulus-related processing, and insensitive to motor processing (40,41).

Second, how can the widespread behavioral effects of hypoxia be explained if central mechanisms are unaffected? One possible explanation is the bottleneck hypothesis - early visual slowing exerts a profound effect on the system as a whole by acting as a bottleneck to later processing. According to this view, virtually all hypoxia experiments involving the measurement of performance and cognition have relied on vision, and it is this modality that is the common denominator between these experiments, rather than the putative disruption of a number of central cognitive mechanisms. The bottleneck hypothesis also offers an explanation for the finding that 'complex' tasks are more sensitive to hypoxia than 'simple' tasks (23). Unlike AFM tasks, complex tasks involve feedback and iterative processing (42). The involvement of these operations raises the possibility of cumulative slowing that is secondary to the original source early in the system. According to this view, the sensitivity of a task to hypoxia depends on the number of operations required to perform the task. A core tenet of the present view is that the effects of hypoxia on vision are intimately related to its effects on performance. This view contrasts sharply with many discussions about the effects of hypoxia on performance. In these discussions, the extreme sensitivity of visual functioning is emphasized, and the sensitivity of cognitive tasks is also emphasized, but the intimate relationship between these parts of the information processing system goes unrecognized.

A second possible explanation is that a single central locus of slowing exists, but it has escaped detection because the AFM is limited to the measurement of stages. The most likely possibility in this regard is the central executive of working memory, since

this mechanism is considered to be critical to a variety of cognitive activities, including reading, reasoning and mental arithmetic (43). A direct test of the effects of hypoxia on this mechanism has not been made, since a different paradigm from the AFM must be used to assess it. However, another part of working memory, the phonological loop (43), has been assessed with a dichotic listening task and found to be unimpaired (25). Neither of these hypotheses can be ruled out at the present time, but we are inclined to favor the first one, if only on the grounds that it seems unlikely that the central executive is sensitive to hypoxia, but not the phonological loop or central AFM stages.

The second issue that needs to be addressed is the generalizability of our results. The level of hypoxia that we habitually use (65% SaO_2) is considered to be severe, and according to McFarland is approaching the zone of potential collapse (44). Indeed, McFarland reports that at simulated altitudes of 18,000-19,000 ft in a hypobaric chamber, SaO_2 is in the range 70-75%, and that this zone represents the threshold for unacceptable performance. Obviously, there is a discrepancy between our observations and this classic description provided by McFarland. The key to this discrepancy may be that, when SaO_2 is free to vary in a hypobaric chamber, there can be no guarantee that it does not continue to fall during the exposure. The rate of fall of SaO_2, the degree of hypocapnia that develops, and the length of exposure, as well as the ultimate SaO_2 level reached, probably influence performance. It is therefore difficult to compare our results, where these factors are controlled, with studies in which they have been allowed to vary.

Our results suggest that brain functioning is largely protected from hypoxia, at least within the time and severity parameters of our experimental method which, it should be noted, induces hypoxic hypoxia. It could be speculated that the sensitivity of vision to hypoxia functions as an early warning system by providing feedback to the organism that hypoxia is developing. Thus cognitive capacity remains preserved to allow escape from the situation. If general brain functioning is protected from hypoxia, then one would expect to find physiological compensatory mechanisms that can offer this protection. Clues to the presence of these mechanisms may have been uncovered in studies involving mild hypoxia (39,45).

The foregoing line of speculation leads to the important question of whether our model can be generalized to another form of hypoxia, stagnant hypoxia, which is encountered in the high G environment. This issue remains to be resolved, but the model appears to fit two situations: the use of vision by pilots to calibrate the amount of G that can be safely pulled during maneuvers, and the use of vision as a metric in centrifuge studies to assess the effectiveness of current (anti-G suits) or prototype (positive pressure breathing) acceleration countermeasures. Vision has been employed in centrifuge studies largely because behavioral measures have proven to be unsatisfactory (46,47,48), and thus little is known about cognitive impairment in these circumstances. The use of event-related brain potentials that are sensitive to hypoxia, such as P300 (39), offers a solution to this problem, since these measures can be obtained without an overt response.

Positive pressure breathing under high G has been proposed as a technique for delaying the onset of unconsciousness. Below this limit, the question arises as to what level of hypoxia may be a limiting factor in sustained high G maneuvers. If our model is applicable to stagnant hypoxia, then it suggests that a pilot could still function despite a certain degree of hypoxia. Allowing a mild degree of hypoxia to develop could have a pay-off in terms of an enlarged G envelope in which the pilot can function.

ACKNOWLEDGMENTS

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Automatic Detection of Cerebral Hypoxia Using Frequency Domain Mapping and Neural Networks

Implications for Use in Smart Garmentry

by

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ABSTRACT:

The development of quantified EEG (qEEG) in the form of frequency domain mapping has provided methods of automated analysis to detect normal and abnormal physiological states as well as definite neuropathological states in the brain. There is considerable importance in the various high risk military occupational environments to be able to detect incipient cerebral hypoxia, in order to prevent incapacitation due to hypoxia in real time.

This paper presents the current data which have been gathered and analysed at DCIEM, NDMC and the Ottawa Civic Hospital in the development of automated models of detecting cerebral hypoxia using frequency domain analysis of EEG. The basic method of analysis of spectral shifts of frequency domain spectra in epochs of 4 seconds of time. The results obtained show the spectral changes in normal wakeful individuals, normal individuals undergoing hyperventilation and volunteers subjected to levels of graded hypoxia.

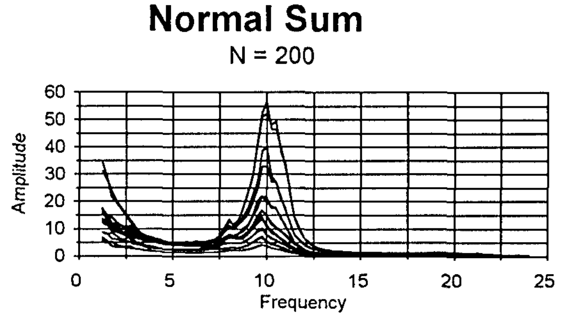
The results from forty eight subjects of average age of 22 years performing hyperventilation as part of clinical EEG showed a large spectra shift in keeping with the slowing seen on time domain EEG.

The results of three subjects exposed to three levels of oxygen saturation showed at 80% saturation an initial decreased peak frequency with increase in amplitude. At 70% saturation, there was a decrease in amplitude with a flattening and widening of the spectral pattern.

INTRODUCTION:

The use of frequency domain EEGs allows the analysis of the background spectra in real time in the determination of the brain state. The method involves sampling the time domain EEG signal in epoch of several seconds and generating the frequency domain spectrum for each of the 16 electrode set. The distribution of the signal densities have been established in large normative databases which can be compared against a real time spectrum to determine the deviation from the normative data. The normal EEG spectrum appears as a peak centered at a median frequency of 9.7 Hz with low frequency components most prominently anterior associated with eye movements.

The application of this method for the detection of



cerebral state in occupational environments such as aviators or divers for the purpose of determining conditions associated with sudden incapacitation can potentially make use of this method.

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The drawbacks of real time EEG is the degradation by artefact due to eye and scalp movement as well as ambient noise from electrical systems and instrumentation.

The occupational conditions most commonly associated with sudden incapacitation are global hypoperfusion due to G forces, cerebral hypoxia related to oxygen supply, or seizures secondary to cerebral hypoperfusion.

Another compounding factor in the detection of state change due to hypoxia is the coexistence of hyper or hypocarbia and its effect on the cerebral vasculature. Our laboratory has conduced studies on spectral shifts with hyperventilation in normal subjects which correlate with the literature (Ref 1), that large low frequency shifts occur with profound hypocarbia independent of hypoxic effects.

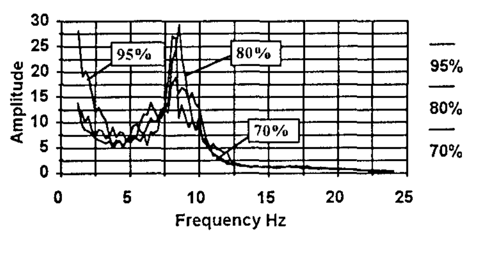
The purpose of this study was to gather spectral data under controlled conditions of cerebral hypoxia to determine the degree and morphology of the spectral shifts and to apply statistical methods to develop a system of automatic detection.

METHODS:

The experimental protocol was carried out at the Defence and Civil Institute of Environmental Medicine (DCIEM) in North York, Ontario, Canada with the offline analysis performed at the National Defence Medical Centre (NDMC) in Ottawa.

The hyperventilation study was performed as part of EEGs performed for screening purposes on young aircrew candidates. The subjects were asked to breath deeply and quickly for three minutes. The spectra were obtained for epoch during which the slowing was maximal. These spectra were compared to the subject's own control spectrum down prior to hyperventilation in a resting state.

The experimental method used normal volunteers between the ages of 20 and 51 who after informed consent were administered nitrogen/oxygen mixtures of decreasing oxygen content in a graded fashion to obtain oxygen saturations of 90, 80 and 70%. The subjects were exposed to each oxygen/nitrogen mixture for 10 minutes washout at room air levels, then 10 minutes transition to allow the subjects to habituate to the new level of saturation, then 20 minutes at specific level of saturate proscribed by the randomised protocol. The protocol was designed to simulate oxygen levels



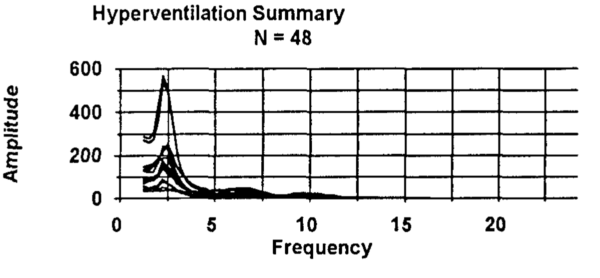
commonly encountered in civil and military aviation environments in order to determine the EEG responses.

Three subjects were studied each at 90, 80 and 70% saturation with randomization of the three hypoxia conditions. Low oxygen mixtures were delivered under continuous finger oximeter monitoring and recording.

Gas mixtures were delivered from high pressure gas cylinders that were analysed for purity. Subjects were exposed to a maximum of 60 minutes of hypoxia, with 20 minutes at 70% being the most severe condition. Two aeromedical technicians were present during all runs, one monitoring the EEG and the other the oxygen saturation.

The facilities used to collect the EEG data for this study were Nicolet Instruments model 1A98 EEG recorders located both at DCIEM. An 80386 processor based computer, and digital data collection and analysis software called BrainLab as supplied by Nicolet located at NDMC.

Each spectral epoch was 4 seconds in length. Artefact rejection was performed manually by selecting the best 15 out of 20 epochs in a representative 80 second segment.



RESULTS:

The results of the spectra measured on 48 subjects who serve as their own controls, who performed three minutes of hyperventilation as part of a normal clinical EEG are shown on the graph below.

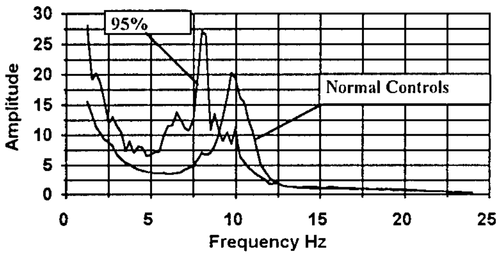
The results from the three subjects performed at DCIEM in August/September 1995, are displayed in grouped spectral data for each level of blood oxygen saturation.

The shift of the average spectrum shows a decrease in mean frequency of 0.5 Hz with morphology changes which have a sequential change characterised at 80% saturation, a downward shift and increase in amplitude. At saturations of 63%, the spectral amplitude decreases and changes in morphology to a bifid pattern.

Summary of hypoxia spectral data for the three subjects shows a similar pattern of spectral change for the hypoxia states, however the control room air state showed a persistent shift when compared with group normals.

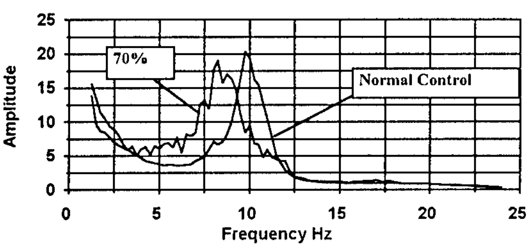
The comparison of the summed spectra with the normal controls shows a persistent shift to lower frequencies in those subjects in whose sequence of hypoxia caused a spectral shift due to hypoxia which seems to persist even if the subject breaths room air.

Normal vs 95%



The comparison of normal control against the summed values of 80% and 70% are shown below.

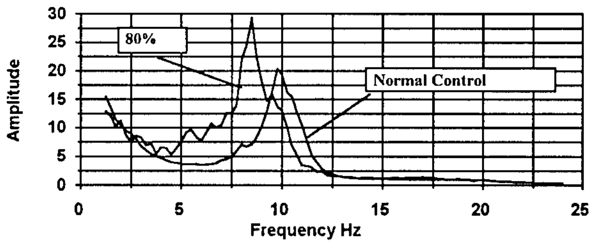
Normal vs 70%



DISCUSSION:

The results presented show that hyperventilation causes a stereotypic frequency shift from a mean peak of 9.7 to 2.5 Hz. The cerebral vasoconstriction causes global cerebral hypoperfusion but the qEEG response is different to that of global hypoxia. In contrast, the spectral shifts with mild to moderate cerebral hypoxia are much less pronounced. This may reflect functional differences in the ability of the cerebral vasculature and parenchymal tissue to autoregulate the delivery of oxygen and metabolites at a cellular level. The data suggests that the qEEG and by implication cortical neurons are disrupted electrically more by disturbances in flow as opposed to lowered oxygen tension.

Normal Population vs 80%



The recovery time of spectral changes from even mild hypoxia may take much longer than anticipated.

The implications for aviation medicine is that reduced flows on the basis of G forces may be more disruptive to brain function than mild to moderate hypoxia. Further experimentation is required to settle this issue.

CONCLUSIONS:

This study although small in terms of numbers of subjects supports the concept of using spectral shifts as a method which can be applied as a real time system of analysing the electrical state of aviators in high risk environments.

The data shows that hyperventilation causes a greater shift than mild to moderate cerebral hypoxia which induces relatively small spectral shifts. The shifts of the hypoxia spectra display non-linear behaviour may require multi-dimensional vector analysis to provide predictive models.

Further study is required in a field environment with G-induced cerebral hypoperfusion to determine whether hypoperfusion or hypoxia has the predominant disruptive effect on electrical activity.

The development of a hardened system to perform real time analysis will require enhanced pre-processing and statistical analysis.

The study will require more subjects and the integration of artefact rejection methods prior to the performance of field trials and integration into military garmentary as a potential monitoring device.

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HEAD INJURIES IN MILITARY PILOTS

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The pilotage of modern military aircraft is highly specific activity which requires a perfect efficiency of the CNS including the coordination between the cortex, subcortical centers and separate effectors. The work of a pilot in the cockpit of current aircraft, typical with a lack of space, large number of controllers and instruments is connected with the necessity of immediate reactions during the information, gravitational and emotional overloads, thus making the demands on pilot's CNS functions enormous. The aim of flight surgeons, assessing the flying ability of the pilots is to admit only the individuals in perfect health condition. The head injury is undoubtedly a serious harm to the delicate brain functions. We should like to share with this competent forum the experience, obtained by the neurological department of the Institut of Aviation Medicine, Prague with the aeromedical assessment of these events in Czech, formerly Czechoslovak Air Force flying personnel during a period 1987 - 1994.

The process of the examination of a head injury is usually as follows: the injured is hospitalized at the surgical department near his home base. After the related injuries are cured (or after a plain observation), the pilot is dismissed and sent to an examination at the neurological department of IAM. The flight surgeon equippes the patient with the necessary documentation, involving the report of the medical facility which provided the primary hospitalization.

The neurologist concentrates on the in time discovery of the potential structural damage of CNS, namely of the presence of paroxysmal phenomena and of the risk of the in-flight loss of consciousness.

Up to 1989 there were about 10-15 pilots with the diagnosis of head injury a year. After the number of Czech military pilots was reduced, it is only some 3-4 individuals annualy. From 1987 to 1994 47 pilots were examined for the head injury. They passed a usual aeromedical examination procedure and in most cases a hospitalization was necessary. The thorough anamnesis is extraordinarily significant. It is concentrated on the circumstances of the injury, as well as on the presence or absence of amnesia, nausea or vomitus. Essential is the documentation of the hospital, which provided the first medical aid and the primary topical neurological finding.

A distribution of the patients to two categories has proved worth: simple head injuries and a head injuries with brain concussion of various degree. A standard procedure includes also additional examinations as are the head radiography and electroencephalography with hyperventilation-test. The routine investigation involves also ophtalmological examination, concentrated on the eyegrounds' status and psychiatric/psychophysiological examination, oriented to the elimination of an organic damage. If needed, the CT of the brain is performed. As far as the greater affection is not found, the patient is dismissed with conclusion "temporarily unable to fly". The duration of this inability can

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vary between 3 to 6 months according to the military regulations. Of course both the relevance of the injury and the clinical course are taken into account. The ability to ground service is also judged individually. Gradually, as the health difficulties fade away, the enhancement of physical load of the airman is recommended. Naturally, the algorithm just presented is modified in accordance with distinctive features of every particular case and the probability of possible complications. Finally, before declaring the pilot's full capability for flying a control examination, comprising of topical - neurological finding, EEG examination and psychophysiological examination, always with separate conclusion about the pilot's capability to fly are carried out. At the same time the airman must succeed in a series of load examinations according following scheme:

1. Standard bicycle ergometry with continual gradual load, aimed to the reaching of maximum load, pertained to the pilot's age group.

2. Tilt table examination, testing the resistance of the organism to the passive position changes. The examination is carried out after calming down of the patient, in the following positions and time intervals respectively: +75 deg. for 12 min., 0 deg. for 6 min., -15 deg. for 6 min., -30 deg. for 6 min., -45 deg. for 2 min. Calming down in horizontal position follows. The heart rate and blood pressure were monitored every single minute.

3. Hypoxic test in an altitude chamber.
   The process is as follows: the examined person sitting still is exposed for 20 min. to the hypoxia corresponding to the altitude of 5000 m. The rate of ascent and descent is 1000 m/min respectively. The basic responses of cardiovascular and respiratory systems are monitored. Should occur any dysfunction of the organism or subjective difficulties, the examination is interrupted immediately and the patient is supplied with oxygen.

After a succesful passing of the loading tests the pilot is declared as capable for flying.

Now an interesting example of head trauma will be presented. A pilot of MIG 21 aged 28, with total 360 flying hours and with very good ratings. His family history was insignificant. He oneself passed just the usual illnesses, never was seriously sick. Aged 10 he broke his right ankle, the healing was normal. He was a non-smoker, alcohol consumed only occasionally, did not drink the cofee.
History of the very injury: While training at a special device for position changing a part of the machine broke and he was shot against the ground. In the fall he sustained a polytraumatism with injuries of the head, chest and left leg. After the fall he was unconscious for a while. Immediately after the event he was transferred to the surgical department of a military hospital, where he spent 7 weeks. He was dismissed with following diagnoses:

- 1st degree brain concussion
- fracture of the mandible and of the left zygomatic arc
- posttraumatic paresis of the left peroneous nerve
- posttraumatic luxation of right incudomalleal articulation, the state after tympanoplasty
- left sided sensorineural hearing loss

After the dismissal from the hospital the pilot was examined in the IAM. In view of the overlasting hearing problems he was examined in a specialized institute for a revision of the tympanoplasty. The outdoor examination at the neurological

department did not ascertain any subjective difficulties. The topical neurological finding was entirely normal, without signs of side assymetry or focal affection. Only the posttraumatic left peroneous paresis persisted. During the EEG examination with the hyperventilation test, just a light asymmetry, displayed as irregularity of the rythm over the left hemisphere was found. The more complex examination at the neurological department was planned. At that time 14 months have passed since the injury.

The patient himself before admission improved his physical condition to fulfill all the requirements to be declared capable to fly after a long-term hospitalization. During a longer bicycle ride he suddenly had had a feeling of derealization ("like he had fallen asleep"). A fall followed, accompanied by the whole body's convulsions, confirmed by a witness of the event. During the fall he sustained a laceration of the upper eye-lid. He was treated in a near-by civil hospital and dismissed after 5 days with following conclusion: state after a slight brain concussion, surgically dressed wound of the upper left eye-lid. Immediately after the dismissal the patient was in good health and denied any difficulties. Consequentially, he was admitted to the IAM's neurological department.

Objective neurological findings were as follows:
Head: non-painful at percussion, periorbital haematoma on the left orbita nearly healed dressed laceration of the left upper eye-lid, minute excoriations by the nose root. Head nerves fading out nystagm when looking to the right, all the other head nerves without affection. The neck free, painless. Standard neurological finding on upper limbs and the abdomen. The left crus in distal ventrolateral part partially atrophic, the musculature slightly hypotonic, the scars after previous wounds on the outer part of the left crus. The flagged flexion of the thumb and hyporeflection L 2 - S 2 on the left side. The stand without disturbances, a slight peroneous walking. Insular hypaesthesia at the left tarsus in the peroneous inervation area.

EEG compared with previous record without any change i.e. only outlasting light asymmetry of the irregular rythm on the left side. Ophtalmological and psychophysiological examination did not reveal any pathological changes. Considering the recent disorder of consciousness and the traceable neurological finding a CT examination was carried out, which proved a dextral hypodense focus with maximum diameter of 3 cm over the roof of lateral brain ventricle, mounted the cranium.
The finding gave evidence for a post-concussion's focus, where the resorpted brain tissue was replaced with cerebrospinal fluid. The finding was a surprise to a certain extent. The final diagnosis was posttraumatic epilepsy and an anti-convulsive therapy was introduced. The pilot was instructed about his health state and its risks and the Aviation Medical Board removed him permanently from flying status. Of course, he lost his driving licence as well. Nowadays the patient is without any problem. Only one attack of uncousciousness appeared during two years despite the continuing medication in consequence of the everyday regime impairment.

The distribution of the head injuries according to the presence or absence of the brain concussion is important, as a significantly affects the duration of the inability for flight, which is about 90 days in the first case and about 60 days in the second case. Whenever we tried to shorten this period in more serious injuries, the patients had problems when performing the load tests, mainly

during the tilt table and hypobaric test, respectively.

The number of head injuries was rather high in the past. Its succesive decrease is related to the splitting of Czechoslovakian federation in 1992 and reduction of flying personell. The presented file does not include 2 cases of complicated polytraumatisms, with structural damage of brain tissue, leading to the apallic syndrome with permanent invalidity. The particular causes of the injuries are in most cases related to the leisure time activities, vacationing or sports. There are also injuries connected with the alcohol consuming, interpersonal conflicts or with car accidents.

To improve the care for Air Force flying personnel suffering from head injuries a good coordination with flight surgeons, providing the thorough medical documentation and an in time sending of the patient for a specialist's examinations is vital. The immediate examination makes possible to register incidental microtraumatisms of the CNS and further monitor their development. A most discussed question is an in time use of computer tomography. In our opinion the examination of a pilot after head injury at a human centrifuge prior to final assessing of his/her fitness for flight could be useful. However, that is nothing but a future question for us at present.

CogScreen-Aeromedical Edition in the Assessment of the Head Injured Military Aviator

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SUMMARY

CogScreen-Aeromedical Edition (CogScreen-AE) is a computer administered and scored cognitive screening instrument designed to rapidly assess deficits or changes in attention, immediate and short-term memory, spatial-perceptual functions, calculation skills, reaction time, simultaneous information processing, and executive functions. The test was designed to detect subtle changes in cognitive functioning, which left unnoticed may result in poor pilot judgment or slow reaction time in critical operational situations. Normative data have been collected on over 800 commercial airline pilots and an equal number of military aviators. This paper will focus on applications of CogScreen-AE in the evaluation of head injured military aviation personnel. The CogScreen test results from a group of 24 mild to severely injured military aviators who were tested up to 90 months following head injury, and five of whom received serial evaluations, are presented. The results of the serial evaluations of five head injured military aviators are also discussed. Results demonstrate the sensitivity of the test to initial injury severity and recovery of function. The combination of conventional neuropsychological instruments and CogScreen-AE may expedite the return of head injured aviators to flying duties and actual control of aircraft.

BACKGROUND INFORMATION

Head injury may be defined by the duration of loss of consciousness and the duration of post-traumatic amnesia (PTA). Post-traumatic amnesia is the time interval between coma termination and the restoration of continuous memory (1). Determination of injury severity is also based on brain imaging and the initial Glasgow Coma Scale score. While the severity of injury is a useful predictor of outcome following closed head injury (2), it cannot substitute for a careful assessment of neurocognitive functioning. Decisions about grounding or returning an aviator to flight status need to be based on objective and valid indicators.

Current aeromedical standards for the United States Navy prescribe specific grounding periods following closed head injury (3). These grounding periods vary from one month for mildly injured personnel to 30 months for severely injured personnel. Individuals with moderate injuries are grounded for 12 months prior to consideration of a waiver of medical standards. These grounding periods were based on conservative estimates of the risk of post-traumatic seizures and cognitive deficits. Head-injured military aviators are required to undergo neurological and neuropsychological consultations prior to being considered for a waiver that would allow them to return to flight status (4).

The neuropsychological evaluation of aeromedical personnel following closed head injury has historically relied on standard psychometric procedures such as the Wechsler Adult Intelligence Scale, the Halstead-Reitan neuropsychological test battery, and a number of specialized tests of memory functioning (5). These instruments assess such areas as abstract reasoning, information processing abilities, memory, visual-spatial skills and intelligence. Interpretation of results from these standard measures are generally made by comparing the individual aviator

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to general population norms, which are sometimes corrected for the influence of age and education. These popular tests were not specifically designed for use with aviators. It is quite possible that the normative samples for these tests are not suitable for the evaluation of aviators. Furthermore, the relationships between test performance and aeromedical risk has never been established for these instruments.

COGSCREEN-AE

In recognition of the limitation of conventional neuropsychological tests in the assessment of aviators, the U.S. Federal Aviation Administration sponsored the development of a computerized cognitive screening battery, CogScreen-Aeromedical Edition (6), a test with extensive aviator norms. The test was designed to measure the cognitive abilities required for skilled aviation performance and to detect subtle changes in cognitive functioning associated with mild brain dysfunction.

TABLE 1

CogScreen Subtests

Backward Digit Span
Math
Visual Sequence Comparison
Symbol Digit Coding
Matching-to-Sample
Manikin
Divided Attention (2 sections)
Auditory Sequence Comparison
Pathfinder
Shifting Attention
Dual Task (2 sections)

CogScreen is a computer administered and scored test which has been found to assess attention, memory, visual perceptual processing, logical problem solving, and reaction time. The battery consists of a series of automated cognitive tests, each of which is self-contained and presented with instructions and a brief practice segment. The battery takes advantage of many of the benefits offered by computerization; improved standardization and scoring, superior timing resolution, and the presentation of dynamic and multiple test stimuli. The program automatically generates 12 alternate test forms that are needed for repeated test administration to the same individual. Software timing provides millisecond level timing resolution.

The battery runs on a standard IBM PC-AT compatible personal computer, with an EGA or VGA graphics card, color monitor, and a light pen. The light pen was chosen to be the primary response input device in order to reduce any advantage of prior computer experience and keyboard use. Furthermore, the light pen allows the examinee to maintain focus on the screen at all times.

The battery consists of 13 subtests. (Table 1) Each test begins with instructions which include examples of test items. This is followed by presentation of practice items. If the subject fails to meet a pre-established level of performance on the practice items, the instructions are repeated. If the practice criteria are met, the subject has the option of reviewing the instructions or proceeding with the test. Tests run for a set length of time or for a set number of items. The instructions are generally self-explanatory and the test administrator rarely needs to provide further directions.

The normative database for the Aeromedical Edition of CogScreen consists of data that were collected from over 700 commercial aviators. In addition, the test has been administered to approximately 1200 military aviators in the United States. Concurrent validity studies have demonstrated expected relationships with analog paper-and-pencil tests; factor analytic studies have demonstrated expected (and meaningful) cognitive constructs; and criterion-related studies have demonstrated high levels of sensitivity and specificity in comparison to traditional neuropsychological instruments.

One of the CogScreen validation studies was conducted with a group of military personnel with mild to

moderate head injuries. The performance of this head-injured group was compared to an age-matched group of pilots. A forward, step-wise, likelihood-ratio logistic regression was used to develop a model for predicting the probability of brain dysfunction (LRPV). The equation used 9 CogScreen variables to arrive at its' predictions. Using this model, 95% of normal pilots were correctly classified (ie, the specificity level), as were 82.9% of the patients with mild brain dysfunction (ie, the sensitivity level) yielding an overall correct classification rate of 90.1%. The CogScreen variables that are incorporated into the LRPV equation will be the focus of our presentation on head injury recovery.

FINDINGS

Over the past two years, 24 patients have been referred to the Psychiatry Department, at the Naval Aerospace and Operational Medical Institute, in Pensacola Florida, for neuropsychological evaluation following a closed head injury. All patients were college educated males. They had a mean age of 28. The majority of patients in this group were 8 months post injury. On conventional testing these aviators scored within normal limits. With the exception of one patient who was evaluated two days following the resolution of a two-week period of PTA, verbal and visual-spatial memory were within normal limits and consistent with observed level of intelligence (mean IQ = 118). The majority of patients had initial Glasgow Coma Scale scores within the 13 to 15 range, while the duration of post-traumatic amnesia varied from less than 5 minutes to more than one month (Table 2). Five patients received serial evaluations, with a mean inter-test interval of 6 months.

A significant relationship was found between injury severity (as measured by the duration of post-traumatic amnesia) and the variables that comprise CogScreen's logistic regression probability value(LRPV) (Table 3). LRPV was also significantly correlated with loss of consciousness. As previously described, the LRPV provides a measure of the probability of brain dysfunction. Specifically, the largest correlations were between the LRPV reaction time measures and duration of post-traumatic amnesia (Table 4). Within this sample, LRPV was not significantly correlated with age, intelligence, months since injury, initial Glasgow Coma Scale or the initial estimate of seizure risk (7).

TABLE 2

Post-Traumatic Amnesia

Duration	# Patients
< 5 Minutes:	7
< 1 Hour:	3
< 1 Day:	6
< 1 Week:	4
< 1 Month:	3
> 1 Month:	1

LRPV was also significantly correlated with the results of the Paced Auditory Serial Addition Task (PASAT). Of the conventional neuropsychological measures, the PASAT has been shown to be one of the most sensitive measures of the information processing deficits associated with head injury (8). Studies have reported the PASAT to be useful in predicting the readiness of individuals to return to work following a closed head injury (9). The PASAT performance of these patients were consistent with both recently published norms which correct for the influence of age and intelligence (10), as well as unpublished military aviator norms. The shared variance between COGSCREEN's LRPV score and the PASAT is encouraging.

TABLE 3

Correlations Between CogScreen LRPV and Injury Recovery Factors

	r Value	p Value
PTA	0.56	0.01*
LOC	0.50	0.01*
GCS	0.32	0.07
AGE	0.05	0.30
Months S/P	-0.15	0.25
IQ	-0.13	0.29
Sz Risk	0.25	0.12
PASAT Avtime	0.57	0.01*

As previously mentioned, five patients were re-evaluated approximately six months following the initial administration of the CogScreen battery (Table 5). For these patients, the results of serial evaluation document that mildly injured patients may demonstrate both stable and normal cognitive performance within the eight months following injury. Stable and normal performance was also demonstrated by standard neuropsychological instruments.

TABLE 4

Correlations Between CogScreen Subtests and Post-Traumatic Amnesia Duration

	r Value	p Value
DATIRTC	0.41	< 0.03
MTSRTC	0.49	< 0.01
SATINRTC	0.49	< 0.01
VSCRTC	0.53	< 0.01
DATIPRE	0.43	< 0.02

TABLE 5

Serial LRPV Results Among Head Injured Aviators

Patient #	Initial Mean = 8 mo. S/P	Follow-Up Mean = 14 mo. S/P
5	0.00	0.00
7	0.10	0.17
8	0.22	0.16
13	0.01	0.00
17	0.00	0.00

DISCUSSION

In summary, the data presented suggest that CogScreen-Aeromedical Edition may function as a valuable tool in the assessment of the head injured military aviator. Although this presentation has focused on the value of CogScreen's LRPV, the battery actually provides a wealth of information about the individual aviator's cognitive functioning. There are 19 measures of speed and 19 measures of accuracy. These scores identify specific cognitive strengths and weaknesses. In addition, the test's base rate analysis provides a measure of level of performance. Unlike conventional tests, CogScreen provides an indication of an aviator's ability to process simultaneous mental operations on measures of dual tasking and divided attention.

Although aeromedical standards reflect a dual concern regarding the post-traumatic risk of seizures and cognitive difficulties, the current data suggest that these issues may be evaluated independently of each other. Our findings suggest that the cognitive deficit reflected by the CogScreen LRPV value is independent of the estimated seizure risk. Although seizure risk may be associated with such variables as dural penetration or focal neurological signs, cognitive outcome is more strongly associated with the initial duration of post-traumatic amnesia. A sensitive test, such as CogScreen, provides both the aviator and the clinician an increased awareness of the subtle cognitive difficulties associated with closed head injury. The test's sensitivity also increases the confidence with which the patient's cognitive recovery can be documented, thereby enhancing the clinical decision process associated with an aviator's earliest possible return to flight status. Efforts are currently underway within the U.S. Air Force and Navy which will obtain medical baseline CogScreen data during the initial aviation physical examination. The head injured aviator's cognitive recovery will then be monitored with reference to their personal age-corrected baseline scores.

One of the advantages of CogScreen, not discussed in this presentation, is its' relationship to skilled aviation performance. The question of how subtle cognitive deficits affect aviation performance can only be answered by studies of the relationship between aviator performance and cognitive test performance in healthy aviators. As we identify the CogScreen variables that are most predictive of poor aviator performance among skilled aviators, additional studies could explore the potentially unique cognitive demands associated with learning to fly.

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Carbohydrate Deficient Transferrin- a New Marker to Evaluate Alcohol Consumption in Pilots

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Summary

To test the possible value of new, comercially available test kits for Carbohydrate Deficient Transferrin (CDT) in an aeromedical setting, a clinical trial followed by an alcohol consumption trial have been conducted at the German Air Force Institute of Aviation Medicine (GAF IAM).
The clinical trial with 268 tests showed that CDT is a valuable and accurate new tool in the assessment of alcohol consumption in otherwise healthy persons.
The alcohol consumption trial showed that tests for CDT can not detect the difference between abstinency and consumption of 25ml of alcohol/ day for three weeks. However, CDTect seems to be more stable than %CDT.

Introduction:

Alcohol:
There are about 2-3 millions of people addicted to alcohol and 10 millions with alcohol-induced organ damage and nearly 41.000 traffic-accidents per year in Germany alone (Seitz, 1993; DHS, 1992; Feuerlein, 1991; Spielberg, 1995) A proven association of alcohol with 10% of all fatal airplane accidents (Li, 1994) underlines the nessecity to investigate the alcohol consumption of military aviators.
As long as it is not successfully treated, alcoholism is disqualifying for German Air Force pilots (Glaser, 1995). The main problem regarding to the difficulty of evaluating the pilots´ consumption of alcohol are cases where alcoholism can not be diagnosed, yet the quantities of alcohol consumed seem to be to large. Here the earlier concept of alcohol abuse has been replaced by `harmful use of alcohol´(Dilling et al, 1991).

Harmful use of alcohol:
To diagnose harmful use of alcohol, harm has to be shown (i.e. liver damage or skin signs or decrements of performance) and a connection with a high intake of alcohol has to be established. Since pilots fear for their licences, possibly harmful dosages (e.g.30g alcohol per day (Aasland, 1987)) tend to remain underreported (Simpura, 1987; Freund and Glaser, 1994).

`Old´ markers of alcohol consumption:
So far the normally used markers of alcohol consumption such as GGT, GPT (ALAT), GOT (ASAT) or mean corpuscular volume of the erythrocyte (MCV) had the great disadvantage of being markers of organ and tissue damage, resulting in only low specifity (Stibler, 1991; Aderjahn, 1993; Goldberg and Kapur, 1994). Mainly the enzymes of hepatic origin tend to be elevated in many hepatobiliary diseases or intoxications other than alcohol (Goldberg and Kapur, 1994; La Grange et al, 1994) and tend to be normal in younger patients abusing quantities known to be harmful (Nystroem et al, 1992).

Carbohydrate Deficient Transferrin (CDT) :
Transferrin is a iron transporting protein (Roth, 1993) with two carbohydrate domains that, together, comprise of seven side chains. Complete side chains are ended by a sialic acid molecule, so that a transferrin molecule can have up to seven sialic acid side chains. Normally, however, transferrin constitutes mainly of pentasialotransferrin (10%), tetrasialotransferrin (60-80%), and trisialotransferrin (10%) (Iffland et al, 1994).

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Transferrin variants with less than three sialic side chains are called Carbohydrate Deficient Transferrin (Stibler, 1991). The mechanism of the forming of the deficient variants is still unclear (Ackenheil, 1993, Kanitz, 1993), but an elevated amount of CDT could be shown in patients consuming more than 50g alcohol per day (Stibler, 1991; Bell et al, 1994b).
The main advantage of the evaluation of CDT seems to be its great specifity (reported to be as high as 97%by Stibler, 1991): It is not elevated in most forms of liver desease (Bell et al, 1993).
The half-life of CDT is around 14 days, the cut-off point is said to be somewhere between 17 (Jaakkola, 1994) and 30 (Iffland et al, 1994; Iffland and Grassnack, 1995), while most studies set it at 20 units per liter for men, for women somewhat higher at 26 U/l.
The first comercially available CDT-test kit was able to measure the absolute level of CDT (CDTect from Pharmacia), while the second method measures the ratio of CDT to total transferrin (%CDT from Biorad).So far the first test is the most frequently used. Wether there really is an advantage in measuring the ratio remains disputed (Bell et al, 1993, 1994a and b; Xin et al, 1992; Kwoh-Gain, 1990).

Since the detection of CDT seemed to offer great opportunities in the evaluation of pilots with signs of liver damage or other signs that might be attributable to excessive intake of alcohol, the reported investigation was initiated.

Aims of the study:
Because there had been mostly clinical trials to prove a sensitivity of up to 82% and the impressive specificity of up to 97% (Stibler, 1991) in which alcoholics where compared to controls, it is evident that the distiction between subgroups of a continous spectrum of alcohol intake is harder to achieve (Goldberg and Kapur, 1994; Allen et al 1994).
So the questions are: Can CDT help in singling out the pilots with harmful use of alcohol?
How accurate is the information gathered by the measurement of CDT?
Should CDT be measured routinely despite the cost of approximately $50 in Germany?

In order to answer the questions, two studies were conducted:
1. A clinical trial of the usefulness of the new diagnostic instrument.
2. A double-blind placebo controlled study to assess the accuracy of the CDT measurement with low doses of alcohol.

Methods and investigation

The clinical trial:
Starting in spring 1994, CDT was measured for every pilot attending his physicals at the German Air Force Institute of Aviation Medicine who fulfilled the set criteria (table 1). The laboratory (Dirr et al) used the first comercially available testkit from Pharmacia, Sweden (CDTect) that produces results in U/l which are roughly equivalent to mg/l. The normally used cutoff point for males is set at 20 U/l.
The pilots were questioned concerning their usual drinking habits and alcohol consumption was quantified in ml alcohol/week.

Table 1

CDT is measured, if
• there are anamnestic hints to suspect inadequate use of alcohol
• the amount of alcohol consumed per week exceeds 300ml
• the value for GGT is greater than 28 U/l
• the value for GOT (AST) is greater than 20 U/l
• the value for GPT (ALT) is greater than 24 U/l
• the value for MCV is greater than 97 fl.

(enzymes measured as usual up to now in Germany at 20°C with normal values for GGT from 4-28 U/l)

Also, 75 unselected candidates for military flying duties and several total abstaining from alcohol were included.
All in all, about 300 tests were performed, of which 268 had complete records and could be analyzed in this study.
Since number of false positive results of the CDT assay are very important to the flight surgeon, all cases with pathological values for CDT were followed to allow a definitive diagnosis (Freund, 1996). Cases with elevated levels of CDT had to present themselves to a complete neuropschological and psychiatric examination with a duration of two days at the GAF IAM.

The alcohol consumption trial
To investigate the effects of low-dose alcohol consumption on CDT values, a double blind trial approved by the ethics committee of the bavarian chamber of physicians was initiated.
For a period of six weeks, twentyone healthy volunteers (military personnel from the Fürstenfeldbruck airbase and officer´s school

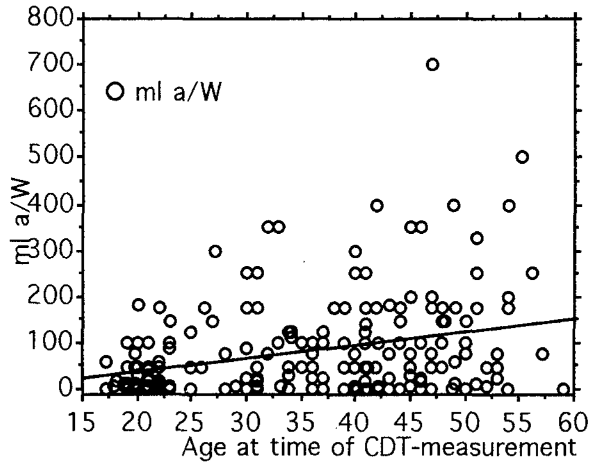
and GAF IAM receiving only a nominal compensation of DM 105) giving informed consent had to follow a diet of complete alcohol abstention except the alcohol (20g per day compared with no alcohol) dealt out for the trial.
The participants had to drink the provided unmarked bottle of beer (Löwenbräu, 1995) every evening.
According to a randomized plan, they were assigned to the group drinking alcohol-free beer for the first three weeks and beer with alcohol for the next three weeks or vice versa.
Venous blood samples were taken before the trial and at the end of every week to allow the measurement of the two commercially available CDT test kits and the liver enzymes GGT, GOT and GPT.
The CDT test kits used were CDTect from Pharmacia, Sweden and %CDT from Axis Biochemicals, Norway.
CDTect provides values in U/l with a cut off point of 20 U/l for males, while %CDT measures only the relative amount of carbohydrate deficient vs. total transferrin with a cut off point of 2.5.%.
Since the results of the CDT assays were completed in september, only preliminary results can be presented here.

Results:

Clinical trial:

During 1994, 268 blood samples from german military pilots or applicants for military flying duties could be included in the study.
All tested persons were healthy white males. The age ranged from 17 to 59 years with a mean of 34.2 (SD= 11.4).
Anamnestic data on alcohol consumption:
The consumption admitted at the physicals was rather low: 80 ml of pure alcohol per week (the equivalent of1.6 l of beer or .8 l of wine per week).
Since the discrepancy between alcohol consumption admitted and recorded is well known (Simpura, 1987; Freund and Glaser, 1994), the data concerning amount of alcohol consumed is interpreted accordingly.
Nevertheless, one can observe lower alcohol consumption in applicants corresponding to the strong correlation between age and alcohol consumption (r= .33).

Figure 1: Correlation between age and alcohol consumption:



Gamma-Glutamyl-Transferase (GGT):
The findings for GGT tended to be rather high (owing to the indication process for the examination of CDT that included elevated liver enzymes). The mean value was 24.3 U/l (measured as usual up to now in Germany at 20°C with normal values from 4-28 U/l) with a SD of 20.7 .
The otherwise unselected group of applicants showed a mean value for GGT of 9.4 U/l.

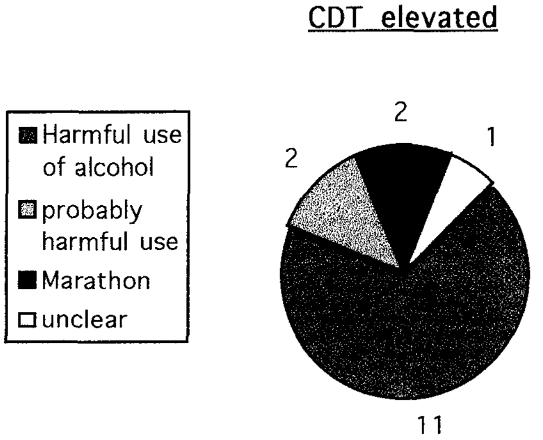
Other liver enzymes:
Mean values for GOT and GPT were 13.2 (SD=6.3) and 19.5 (SD=12.1). The liver enzymes were lower in applicants and those abstaining from alcohol.

Mean corpuscular volume (MCV) of the erythrocytes:
MCV averaged at 92.1 fl (SD= 3.8) and was lower in applicants (90.1 fl, p<.0001) and higher in those admitting a consumption of more than 150 ml/week (93.9 fl, p=.002).

CDT:
In our group of people who were mostly selected because of other laboratory abnormalities, the values for CDT had a mean of 12.6 U/l (SD= 5.9). They were somewhat lower for abstaining persons (11.7 , p=.07 , statistically not significant) and higher for people admitting consumption of more than 150 ml alcohol per week (15.3 , p=.03).
While there were significant correlations to be observed between CDT and MCV (r=.24) and admitted alcohol consumption (r=.28), no correlations could be found between CDT and liver enzymes or age.

We found 16 persons with elevated CDT values.
The follow up led to the results presented in figure 2. In eleven cases the diagnosis of harmful use of alcohol (at the time before the blood sample was taken) could be established and consequences were taken.
In two cases the diagnosis was probable but not proved.
In one case, the pilot's noncompliance with the follow up investigation led to disqualification without the chance to establish a diagnosis.
In two cases, the marathon training the pilots were engaged in (with the resulting metabolic changes) was the most probable explanation for the elevated CDT levels (Freund, 1996).

Figure 2:



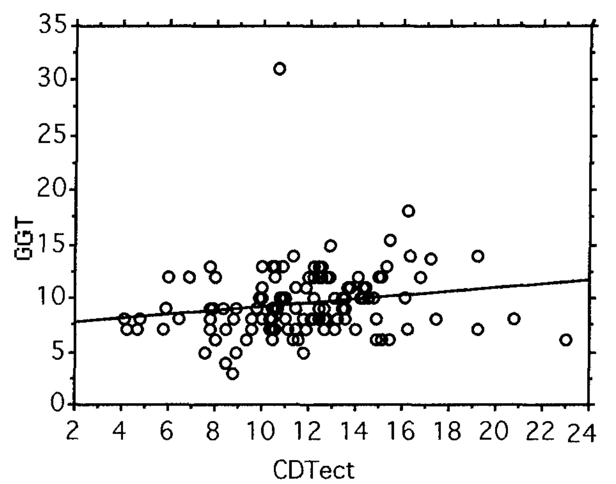
The accuracy of the CDTect method to detect harmful use of alcohol in our case therefore was 11/16 or 69%.

Alcohol consumption trial:

From altogether 21 participants, 18 successfully completed the trial. Two had to be excluded because of elevated liver enzymes and one broke off because of diarrhea he attributed to the beer.
The 18 people were all healthy white males without history of liver disease or problems related to alcohol.
They were aged 20 to 41 years (mean 29.5, SD= 6.2) and reported an alcohol consumption of 72 ml per week, roughly the same as the pilots in the clinical trial. Upon admission to the trial their MCV was 88 fl (much lower than the 92.1 fl of the pilots in the clinical trial, p= .0002), their GGT value was 10.8 U/l (lower than the 24.3 of the pilots in the clinical trial, p= .0001). Their GOT levels averaged 10.4 U/l (lower than the 13.2 of the pilots in the clinical trial, p= .0001). Their GPT levels averaged 10.3 U/l (much lower than the 19.5 of the pilots in the clinical trial, p= .0001). Despite the markedly different liver enzymes and MCV, the CDT levels at the beginning of the trial were the same (12.4 U/l vs 12.6 in the clinical trial).

The liver enzymes during three weeks of moderate alcohol consumption:
While all enzymes started at a low level, no meaningful response to three weeks of alcohol consumption could be detected. For example, the average value for GGT after three weeks of alcohol-free beer was 9.1 U/l (SD= 2.6) and after three weeks of one bottle of normal beer daily (25 ml alcohol/ day) averaged 9.3 U/l (SD= 2.7).

CDTect after three weeks of moderate alcohol consumption:
While the CDTect values averaged 11.8 U/l (SD= 2.8) after three weeks of abstention (alcohol free beer), the value after three weeks of 25 ml alcohol daily was slightly lower: 11.4 U/l (SD= 3.0). The difference was insignificant (p= .64).
There were only statistically insignificant insignificant correlations between CDTect values and alcohol consumption or age or MCV.
The only correlation to reach the level of statistical significance was to be found between GGT and CDTect (r= .177, p= .048):
Figure 3: Regression CDTect/ GGT:

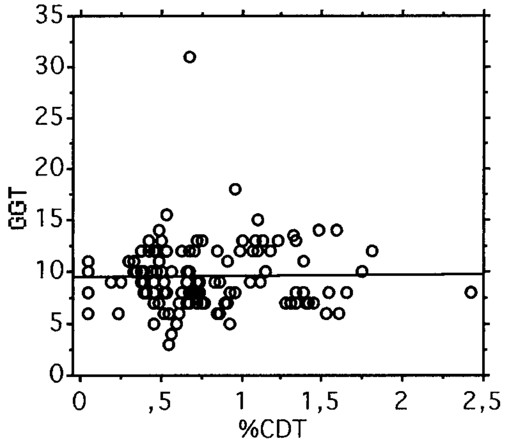


There were only statistically insignificant correlations between CDTect values and alcohol consumption or age or MCV.

The only correlation to reach the level of statistical significance was to be found beetween GGT and CDTect (r=.177, p=.048). Figure 3 shows, that the higher the GGT in our sample, the higher the value for CDTect tended to be. No simple causal explanation can be made (a common cause might be alcohol consumption, but neither hard data nor a 'Gold-standard' laboratory test exists to prove this causal connection).

%CDT after three weeks of moderate alcohol consumption:
The %CDT levels after three weeks of abstention (alcohol free beer) averaged .67 (SD= .371) and after three weeks of 25 ml alcohol per day averaged .77 (SD= .4). This difference was not statistically significant (p= .29).
The correlation between CDTect and GGT could not be detected for %CDT/ GGT (r= .02, p= .84)

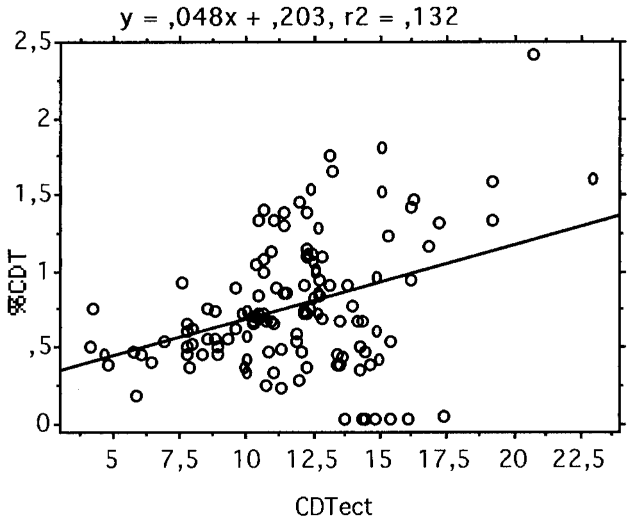
Figure 4: Regression %CDT/ GGT:



This graph shows that %CDT is independent of GGT or that it is exspected that liver damage of unknown origin does not cause changes in %CDT.

The correlation between CDTect and %CDT:
There exists a correlation between CDTect and %CDT (r= .36, p= .0001), as is to be exspected. But if this correlation is compared to the one between the liver enzymes GOT and GPT in the trial (r= .45, p= .0001), it is astonishing to see that the two different liver enzymes correlate stronger than the two methods to measure the same phenomenon of carbohydrate deficiency of the transferrin molecule.

Figure 5: Regression between CDTect and %CDT:



Discussion:

The clinical trial showed the new alcohol marker CDT to be a valuable and accurate tool, especially in cases where the older markers such as the liver enzymes were elevated.
The missing correlations between the liver enzymes and CDT have been attributed to the fact that CDT is no marker of tissue damage but of processes directly linked to the consumption of alcohol (Goldberg and Kapur, 1994). So, this missing correlation could be exspected to be a sign of the usefulness of this new marker.
The reported accuracy of 69 % is very satisfactory, if one takes into account that CDTect was not used to distinguish between (already diagnosed) clinical alcoholics and healthy persons, but to search for persons with harmful use of alcohol who were apparently otherwise healthy enough to be pilots.
If one looks further at the cases that were not counted as diagnosed accurately, one sees three cases that were at least not totaly wrong: Two where the diagnosis of harmful use of alcohol seemed probable but not enforcable in the environment of intelligent (if not belligerent) pilots, and one, where the exact diagnosis was not necessary to ground the pilot.
This leaves two cases, where the CDTect surely did detect something that is not connected to the use of alcohol: Two persons engaged in training in long distance running. Here one could speculate, that their increased iron metabolism caused an increase in absolute levels of CDT.

Correspondingly, the controls with %CDT and the more qualitative manual isoelectric focusing for CDT showed normal results (important: While the CDTect level was still elevated!), so that the elevated reading for CDTect were accepted as false positive.
A rewiew of the literature shows other reasons for elevated CDT levels: Genetically determined D-variants of transferrin, that are rare among whites (Stibler, 1988; Bean and Peter, 1994) or children with Carbohydrate-deficient-glycoprotein-syndrome (Stibler, 1994) or Retinitis pigmentosa (Potter, 1994).
Also false positive results are found in patients suffering from primary biliary cirrhosis of the liver or chronic persisting hepatitis (Stibler, 1991). Altogether, these false positive results occur only seldomly (Iffland and Grassnack, 1995; Heil et al, 1994).
<u>The alcohol consumption trial</u> shows clearly that the two methods to detect CDT cannot detect small quantities of alcohol intake.
The design was carefully laid out to recruit dependable volunteers who could be trusted to remain abstinent for the required period of time. The small compensation was not announced before the trial started. The amount of alcohol was rather small, but people not accustomed to alcohol wouldn´t drink two or more bottles of beer daily for three weeks.
This was done to exclude difficulties reported by other groups (Lesch, 1994) who couldn´t trust their participants.
Due to the double blind randomized design with alcohol free beer serving as control, other effects than alcohol can be excluded.
All in all, the input into the alcohol consumption trial seems to be reliable.

Effects of 50g of alcohol per day on CDT values have been reported frequently (Bell, 1994a, b).
Since no effects of 20g of alcohol per day could be detected, one clearly has to suspect a higher consumption of alcohol in cases, where CDT levels are elevated.

The correlation between CDTect and %CDT is not as high as could be exspected. Anyway it seems sensible to compare their quality. From the theoretical background the possibility to measure only the percentage of carbohydrate deficient vs total transferrin seems intriguing, because all causes that alter the level of total transferrin do not matter anymore.
This abovementioned lack of correlation between CDTect and %CDT may be due to the fact that differences or changes in the concentration of total transferrin may lessen the correlation between the two methods.
This fact clesrly illustrates that the two methods or their results are not easily exchangeable.
But if one computes the standard deviation as percentage of the measured value, a greater stability of the CDTect measurement becomes visible.
Precluding final analysis, CDTect would be at advantage.
Our procedure to test for CDT only in cases where other indicators lead to further investigations of the alcohol consumption has the advantage to be relatively cheap. A big disadvantage, however, is due to the fact, that the reported good sensitivity of CDT is lessened because CDT is measured only in cases where the sensitivity of the other markers has produced a positive result. In other words the combined sensitivity is the product of the single sensitivities (e.g. .7 x .7= .49, which is much worse than the single sensitivities). With this procedure, the specificity is optimized at the cost of sensitivity.
Therefore, the implementation of CDT only as the ´second´ method will lead to an underreport of harmful use of alcohol.
Especially in areas where security has to be high, this is not acceptable, so that the use of CDT measurements as a routinely used screening device is recommended.

Conclusion:

The analysis of CDT to determine the cause of unclear liver damage is useful and accurate.
CDTect seems to deliver stabler measurements than %CDT, both can not distinguish between total abstinency and consumption of 25 ml alcohol (0.5 l beer) per day.

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The Role of Linear Acceleration in Visual-Vestibular Interactions and Implications in Aircraft Operations.

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Summary

While considerable attention has been given to visual-vestibular interaction (VVI) during angular motion of the head as might occur during an aircraft spin, much less attention has been given to VVI during linear motion of the head. Such interaction might occur, for example, while viewing a stationary or moving display during vertical take-off and landing operations. Research into linear VVI, particularly during prolonged periods of linear acceleration, has been hampered by the unavailability of a programmable translator capable of large excursions. We collaborated with Otis Elevator Co. and used their research tower and elevator, whose motion could be digitally programmed, to vertically translate human subjects over a distance of 92.3 meters with a peak linear acceleration of 2 meters/sec^2. During pulsatile or sinusoidal translation, the subjects viewed moving stripes (optokinetic stimulus) or a fixed point source (light emitting diode, led, display), respectively and it was generally found that : (1) The direction of linear acceleration relative to the cardinal head axes and the direction of the slow component of optokinetic nystagmus (OKN) determined the extent of VVI during concomitant stripe motion and linear acceleration. Acceleration along the z head axis (A_Z) produced the largest VVI, particularly when the slow component of OKN was in the same direction as eye movements produced by the linear acceleration and (2) Eye movements produced by linear acceleration are suppressed by viewing a fixed target at frequencies below 1.0 Hz. But, above this frequency the suppression produced by VVI is removed. Finally, as demonstrated in non-human primates (Paige and Tomko, 1991b), vergence of the eyes appears to modulate the vertical eye movement response to linear acceleration in humans.

Introduction

Many studies have shown that VVI occurs during angular acceleration of the head while the subject is viewing a fixed or moving target. These studies have been reviewed elsewhere (e.g. Guedry and Correia, 1978). While important, it is rare in aircraft or aerospace operations, that vestibular stimulation results from angular acceleration acting without concomitant changes in linear acceleration. Often, only changes in linear acceleration occur. There have been some studies of VVI during active and passive angular head motions in increased, reduced or changing gravito-inertial environments (Clement et al., 1986; Clement et al., 1992). Moreover, there have been some studies of VVI during exclusive linear acceleration using horizontal translators (Paige and Tomko, 1991; Wall et al., 1992; Lathan et al., 1995). Paige and Tomko (1991a,b), studying the linear vestibulo-ocular response (LVOR) in squirrel monkeys, observed several interesting phenomena related to the LVOR and VVI. First, they noted that during sinusoidal earth horizontal translation , the magnitude of the LVOR was independent of the "swinging vector" produced by the changing resultant vector due to the vector sum of the time changing linear translation and the acceleration vector due to gravity. Second they noted that the magnitude of the LVOR was function of eye vergence and third they noted that visual suppression of the LVOR was frequency dependent. That is, visual suppression of the LVOR was decreased at frequencies above 1.0 Hz presumably because the visual oculomotor system's performance deteriorates at higher frequencies and therefore the visual response does not "clamp" the vestibular response.

In contrast to these earlier studies, we have chosen to study visual-vestibular interaction during changing linear acceleration where we can direct the vector along any head axis but vary only its magnitude about the earth's constant 1g bias. Thus,

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we have conducted two sets of experiments using a long excursion (92.3 meters) vertical linear translator. This excursion capability also enabled us to provide peak linear acceleration of 2.0 meters /sec^2 (0.2g) at 0.1 Hz. Both sets of experiments were conducted in a programmable motion profile elevator at the Otis Elevator Research Facility. The first set of VVI experiments investigated the role of direction and magnitude of linear acceleration on the OKN response. The second set of experiments investigated the frequency response of the LVOR and role of visual fixation on the LVOR. Results from the first set of experiments have been presented elsewhere (Correia et al., 1993) but will be summarized here and preliminary results from the second set of experiments, just completed, will also be presented .

Methods

VVI - Optokinetic nystagmus and vertical linear acceleration

Each of five subjects seated in a chair on an elevator was pre-positioned so that either their front-back (x), left-right (y) or vertex-base (z) head axis was aligned with gravity. Only the z-axis and y-axis results will be presented here. The elevator was darkened and the subjects viewed a screen (1 meter in front of them) onto which moving stripes were projected. The stripe velocity was 60 deg./sec. Vertical (VOKN) and horizontal (HOKN) optokinetic nystagmus was produced. The horizontal and vertical components of eye movements were recorded using infra-red video (ISCAN) techniques and eye position was simultaneously digitized. After the onset of either VOKN or HOKN, each subject was accelerated [using a pulsatile linear acceleration profile (8 sec. duration; 0.2g in magnitude)] upward and decelerated within 92.3 meters, using the same waveform. The protocol was repeated as the elevator returned to ground level. Thus, each subject received combinations of HOKN and VOKN and linear acceleration forward (+Ax), backward (-Ax), leftward (+Ay), rightward (-Ay), upward (+Az), and downward (-Az). Head acceleration was determined by linear accelerometers mounted in the elevator. The eye position of one eye was digitally differentiated to produce eye velocity and the slow phase eye velocity (SPV) was scored for 4 sec. before and 4 sec. after the onset of acceleration and deceleration. In one set of analyses, the HSPV and VSPV was binned into 0.2 sec intervals and the resultant eye velocity vector magnitude and angle was calculated. In a second set of analyses, mean peak SPV was calculated using 1 sec. bin width intervals. Percent change between mean OKN SPV during 4 sec. before and 4 sec. after the onset of acceleration and deceleration was calculated and is presented in Fig. 1.

VVI - LVOR while viewing a fixed target

Seven subjects were seated in the pre-positioning chair as described in the first set of experiments. As in the first set of experiments, extreme care was taken to insure that the subjects' heads did not move during the linear motion. Each subject's head was secured to the chair using a bite bar and a flight helmet fitted with a rigid head mold. Each subject was pre-positioned so that the acceleration acted along either the z or y head axis. The waveform of stimulation was different from the first set of experiments. Each subject was exposed to sinusoidally varying linear acceleration of peak magnitude of 0.7, 1.5 or 2.0 meters/sec^2. Frequencies used were 0.1, 0.2 0.5, 1.0 and 2.0 Hz. While oscillating, the subjects were exposed to three visual conditions in a randomized order. They were asked to view a point source of light (led) at either 8.7 or 18.1 centimeters in front of them. Additionally, the subjects, while in the dark, were asked to fixate on an imaginary target on the horizon in front of them. The first two conditions will be referred to as near led and far led, respectively and the third condition will be referred to as no led. Preliminary examples of responses during these conditions are presented in Fig. 2.

Results

VVI - Optokinetic nystagmus and vertical linear acceleration

Figure 1 summarizes percent change in OKN slow phase velocity (SPV) as a function of stripe direction and linear acceleration direction. Two directions of linear acceleration are presented; acceleration directed along the left - right interaural axis (A_y) and acceleration along the vertex base head axis (A_z). Upward and leftward acceleration are denoted by +Az and +Ay, respectively. Downward and rightward acceleration are denoted by -Az and -Ay, respectively. Percent change in OKN SPV before and during linear acceleration is shown when: stripes were moving up, producing SPV up; down producing SPV down; left producing SPV left and right

producing SPV right. Acceleration up (A_Z) produces a LVOR with SPV down and acceleration right (A_y) produces a LVOR with SPV left. LVOR SPV is in the opposite direction when the linear acceleration is down and to the left.

Fig. 1. Percent change in OKN SPV resulting from linear acceleration. This figure is redrawn from Fig. 1-B in Correia et al., 1993.

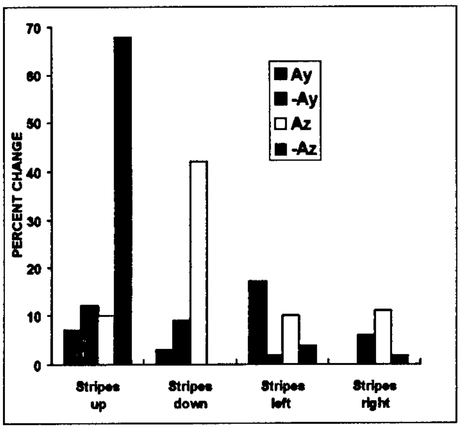
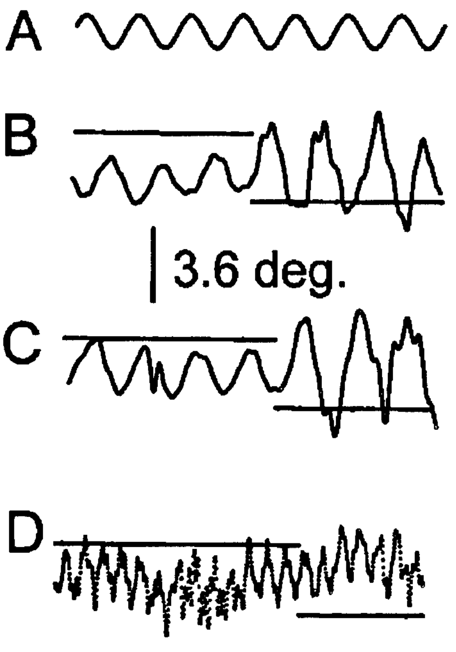


Fig. 1 shows that when acceleration was directed along the vertex-base head axis (Az) and when the acceleration was directed so as to produce a SPV in the same direction as the OKN SPV (acceleration down (-Az) and stripes up or +Az and stripes down) the response increased 68 and 42 %, respectively. However, for -Az and stripes down and +Az and stripes up, the OKN SPV did not decrease, but was zero and 10%, respectively. When the acceleration was directed along the interaural axis, its direction and magnitude did not modulate the HOKN more than 17% (horizontal striped bars in Fig. 1)

VVI - LVOR while viewing a fixed target

Fig. 2 presents horizontal eye position during oscillation at (B-C) 0.1 Hz (±2 meters/sec^2) and (D) 1.0 Hz (±2 meters/sec^2). Panel A is the accelerometer trace indicating A_y that produced the response in Panel B. It can be noted that the horizontal LVOR (Panel B) is 180 degrees out of phase with acceleration. That is, as the subject was accelerated left the eye moved to the right. About midway through the oscillation sequence the near led was turned off and the subject was instructed to continue fixating on where he imagined the led to have been in space. Led on is indicated in all panels by the high level of the superimposed pulse. The low level of the superimposed pulse indicates that the subject was in complete darkness.

Figure 2. Eye position during A_y acceleration while viewing targets at different distances and at two different frequencies. The calibration bar for magnitude of eye position applies to Panel B-D. The eye movement response and accelerometer signal were digitally filtered using a 2 - pole Butterworth filter with a cut-off frequency five times the frequency of the signals. No attempt has been made to correct for head movement in these traces.



It can be clearly seen that eye position is decreased when the subject is fixating on either the near (Panel B) or far (Panel C) led. This is not the case, however when the frequency of oscillation is one order of magnitude higher (Panel D). The eye position is not suppressed during viewing the near led while oscillating at 1.0 Hz.

Discussion and Conclusions

The results from the vertical linear acceleration - optokinetic stimulation study, summarized in Fig. 1, suggest that vertical translation strongly influences the SPV of VOKN when the linear acceleration component due to translation acted along the vertex-base head axis. However, the effect

was asymmetrical. Stripes down-acceleration up and stripes up acceleration down produced large increases in VOKN SPV in all subjects and mean changes of 42 and 68%, respectively. But the opposite conditions, stripes up - acceleration up and stripes down - acceleration down produced changes of 10 and 0%, respectively. That is, the VOKN SPV during acceleration was approximately the same as before acceleration began. This finding, using a vertical translator, is essentially the same as other studies (Wall et al., 1992; Lathan et al., 1995) of the effects of sinusoidal horizontal translation on VOKN. Thus It appears that linear acceleration can augment the SPV of an ongoing VOKN but not decrease it; a non-linear interaction. But it does not seem to matter whether the linear acceleration is swinging through the subject's sagittal head plane (horizontal axis translation) or acting only along the z head axis. This result is opposite that of VVI combining VOKN and angular acceleration. Clement et al. (1992) found that when the SPV produced by angular head motion and the SPV produced by VOKN were in opposite directions, the resultant SPV was decreased but when the SPVs were in the same direction the resultant SPV approached the velocity of the OKN without rotation.

It is well known in aerospace medicine that in the absence or visual cues, the vestibular system can provide erroneous cues and lead to spatial disorientation (reviewed in Love and Correia, 1980 and Guedry and Correia, 1978). The results of VVI involving optokinetic visual stimulation during linear (presented herein) and angular acceleration (Clement et al., 1992) reminds us that we must be aware of the fact that vestibular stimulation can modify an optokinetic visual response and possibly the perception of a speed of a visual surround.

A qualitative preliminary analysis of the results of our human VVI studies of the LVOR while in the dark and while viewing a target (summarized in Fig. 2) are very similar to those of Paige and Tomko (1991a,b) who studied the LVOR and VVI during horizontal linear translation. Also, It appears that during vertical linear translation, *like* during angular acceleration, VVI (see Guedry and Correia, 1978) fixation of a head mounted target suppresses the LVOR for frequencies below 1.0 Hz. Above 1.0 Hz, where the LVOR probably normally occurs, the suppression is removed (see Panel D in Fig. 2).

While the magnitude of the LVOR is much smaller than the angular VOR, the threshold for blurring of aviator helmet mounted instrument arrays in might be reached when LVOR magnitude is increased during convergence and AVOR is present during high frequency turbulence with concomitantly acting linear and angular acceleration.

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EXTENDING THE RANGE OF VISION TESTING: THE SMALL LETTER CONTRAST TEST

by

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SUMMARY

Recent evidence suggests that small letter contrast sensitivity (CS) is more sensitive than visual acuity (VA) to defocus, luminance, binocular enhancement, and visual differences among pilot trainees. It would be valuable to make this test available for general use. We developed a hard copy (letter chart) version called the Small Letter Contrast Test (SLCT) and evaluated its sensitivity and reliability in comparison to standard vision tests. The SLCT has 14 lines of letters with 10 letters per line. The letters are of constant size (20/25 at 4m), but vary in contrast by line in 0.1 log steps (0.01 log units per letter). Normal room illumination is used. The SLCT was evaluated in 16 subjects under various conditions (spherical and astigmatic blur, low luminance, two eyes vs. one) to determine test sensitivity and reliability, and in patients with clinical conditions. Scores were compared to those obtained with standard tests of VA (Bailey-Lovie) and CS (Pelli-Robson). SLCT scores were similar to previous measures, and retest reliability was one line. The SLCT was more sensitive than VA to spherical and astigmatic blur, low luminance, and vision with two eyes vs. one. Greater sensitivity of the SLCT endured despite correction for variability. The SLCT also was more sensitive than standard tests to visual loss from early cataract, keratoconus, corneal infiltrates, edema, and amblyopia. The SLCT is a powerful approach for revealing subtle visual loss which may be undetected by standard clinical techniques. The SLCT will prove useful for monitoring vision in refractive surgery, cataract, corneal and macular edema, optic neuritis, and for evaluation of candidates for unique occupations like aviation.

INTRODUCTION

Optimal visual acuity (VA) is the goal of clinical vision care. Refraction of the eye, detection, diagnosis and treatment of ocular disease, and refractive surgery share the common goal of achieving best VA. The effectiveness of this approach is predicated on the fact that VA is a sensitive index of defocus. Blur causes a reduction in VA, and this reduction is proportional to the amount of blur. But blurring the retinal image also reduces the contrast of higher spatial frequencies. Due to the steep slope of the spatial contrast sensitivity (CS) function near the acuity limit, a loss of VA is associated with a greater loss of CS for higher spatial frequencies.

This principle is illustrated in Fig. 1 which shows that 1D of defocus shifts the descending limb of the CS function downward and to the left. The shift leftward along the spatial frequency axis represents the loss of VA. The shift downward along the contrast dimension demonstrates the greater loss of CS for higher spatial frequencies.

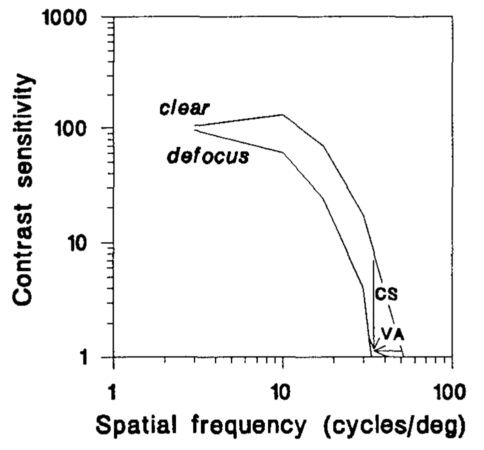

Figure 1. Defocus effects on visual acuity and high spatial frequency contrast sensitivity.

The greater loss of CS than VA suggests that small letter CS may provide a more sensitive index of blur. In previous studies, we used letters displayed on a computer monitor to show that small letter CS is more sensitive than VA to small amounts of blur,[1] subtle changes in the luminance of the stimulus,[2] vision with two eyes compared to one,[3] and for identifying visual differences among pilot trainees.[4] To make this test available for general use, we developed a hard copy (letter chart) version called the Small Letter Contrast Test (SLCT). This paper describes the design of the SLCT, its reliability, and its sensitivity for

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detecting differences from normal and change within patients over time.

METHODS

The SLCT is generated from computer software (Adobe Photoshop version 2.0.1) on a Macintosh Quadra 800 computer. Helvetica bold font is used in grey scale mode which affords 256 grey levels on white background. The SLCT is printed from a Kodak XL 7700 continuous tone digital printer which uses a thermal dye sublimation process. Each SLCT is printed on two sheets of Kodak 8½ x 11" Ektatherm print paper, trimmed and mounted to a single sheet of white gator board (12" x 18"; Fig. 2).

Row											LogCS
1	D	R	E	Z	U	F	V	N	H	P	0.0
2	R	P	F	D	U	N	Z	E	V	H	0.1
3	H	R	P	E	D	V	Z	N	F	U	0.2
4	Z	E	D	H	P	U	V	R	N	F	0.3
5	H	P	F	D	N	V	R	E	V	H	0.4
6	R	Z	F	D	P	N	U	E	V	H	0.5
7	V	D	H	P	E	N	R	H	U	Z	0.6

Row											LogCS
8	U	R	N	E	D	Z	H	F	V	P	0.7
9	N	V	Z	F	H	E	P	R	D	U	0.8
10	D	V	N	Z	R	H	F	U	P	E	0.9
11	P	H	V	D	F	U	E	Z	N	R	1.0
12	R	V	U	N	D	P	H	Z	E	F	1.1
13	F	R	E	U	P	Z	H	D	V	R	1.2
14	E	R	P	D	N	Z	F	U	V	H	1.3

Figure 2. The Small Letter Contrast Test (letter spacing and contrast levels not to scale).

As illustrated in Fig. 2, the SLCT consists of 14 lines of letters with 10 letters per line. Like the Bailey-Lovie[5] and EDRTS[6] VA charts, the SLCT has a logarithmic progression from top to the bottom. However, unlike VA, the letters are of constant size (approximately 20/25 at a 4 m viewing distance), but vary in contrast, by row, in 0.1 log unit steps. Credit is given for each letter read correctly[7] (0.01 log unit per letter). As noted earlier, small letters are used to: (1) test high spatial frequency channels like those used for VA, and (2) take advantage of the steep slope of the CS function for which small changes in VA are associated with large changes in CS.

Normal overhead room illumination (fluorescent or incandescent) is used on the SLCT. Fig. 3 illustrates logCS scores computed from photometric measurement of the luminance of individual SLCT letters and their immediate background (Pritchard 1980 photometer). Measured logCS scores are in good agreement with intended values of 0.1 log unit per line, and measured scores remain constant over a fairly wide range of photopic room luminances (50 to 200 cd/m^2). However, SLCT scores from human observers vary in proportion to luminance over this range.[2]

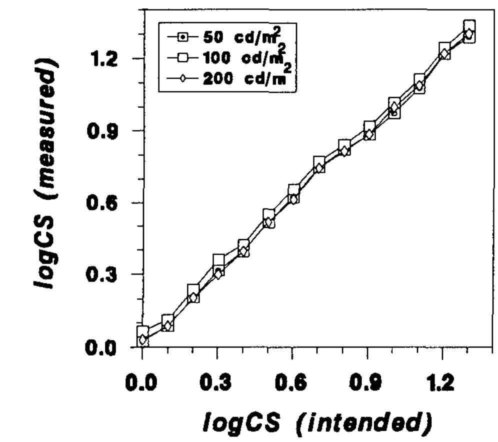

Figure 3. Photometrically measured logCS values are plotted against intended values for three luminances,

To evaluate the sensitivity and reliability of the SLCT, performance on this new test was compared to that obtained with standard tests of visual function. High and low contrast VA (Bailey-Lovie acuity charts),[5] large letter CS (Pelli-Robson chart),[7] and small letter CS (SLCT) were measured monocularly in 21 subjects with normal vision (age 23 to 60 years) to establish mean values and confidence limits for normals. More extensive measurements were obtained from 16 of the 21 subjects (age 23-35) to assess the sensitivity and reliability of each test to several conditions in which vision was compromised by small amounts. Subjects were tested under the following conditions in this order: (1) monocularly (right eye) with best optical correction, (2) low degree of spherical blur (+0.5 D) to simulate low myopia which would preclude an officer candidate from being accepted for pilot training, (3) low degree of astigmatic blur (+1 D x 90), also a failure criterion for pilot training, (4) low level of photopic luminance (6 cd/m^2) to represent the luminance of a night vision goggle display, (5) binocularly to compare to monocular scores, and (6) again monocularly with best correction to assess retest reliability.

Each subject initially was refracted to best VA and then tested in a single session in a vision laboratory illuminated by overhead fluorescent lighting under rheostat control.

The subject was seated comfortably and wore a trial frame such that the optical correction and different power lenses (+0.5 D sphere and +1 D x 90) and filter (low luminance condition) could be placed before the right eye. The viewing distance for high and low contrast VA and the SLCT was 4 m, while the Pelli-Robson chart was viewed at 1 m, as recommended by the manufacturer. Since each vision chart has two versions with different letter sequences, the letter sequence for each chart was alternated between trials to discourage learning effects. The luminance from the white background of the letter charts was 100 cd/m.[2] In addition to these measurements from normal subjects, several observers with subtle visual loss from various conditions also were tested, but without induced blur or low luminance. Informed consent was obtained from all subjects after protocol review by our institutional review committees.

RESULTS

Normative Data

A clinical vision test can be used to determine if vision *differs from normal* or *changes over time.* These are separate issues requiring distinct statistical comparisons. For example, a patient presents with a history of refractive surgery, and testing is conducted to determine if vision is normal on each test. Vision is considered below normal if scores fall below the 95% confidence limits for normal observers (Table 1).

Table 1
Detecting Differences from Normal*

Vision Test	Mean ± 2SD (mean Snellen VA)	Below normal
High contrast VA	-0.11 ± 0.12 (20/16)	20/21 or less
Low contrast VA	0.00 ± 0.14 (20/20)	20/28 or less
Pelli-Robson	1.88 ± 0.17	1.70 or less
SLCT	1.21 ± 0.18	1.02 or less

*Normal observers tested monocularly (n=21, age 23 to 60 years).
†Decimal units are logMAR for VA and logCS for Pelli-Robson and SLCT.

To determine if the same patient's vision *changes over time,* vision is assessed on successive occasions to see if the change in vision falls within the 95% confidence interval for change in normals. This interval, known as the coefficient of repeatability,[9,10] includes 95% of differences between scores in normal subjects. Table 2 shows the coefficient of repeatability in log units for each test, and a significant change in vision in terms of lines of letters. A loss of about one line of letters represents a significant decrease in vision on each test.

Table 2
Detecting Change Over Time

Vision Test	Repeatability (log units)*	Significant change (lines on chart)†
High contrast VA	0.06	4/5 line
Low contrast VA	0.07	4/5 line
Pelli-Robson	0.12	1 line
SLCT	0.11	1 line

*Coefficient of repeatability=2.13 x SD of differences between two scores.
†For VA and SLCT one line=0.1 log unit; for Pelli-Robson one line=0.15 log units.

Test Sensitivity

Fig. 4 shows results from normal subjects (n=16) tested with a small amount of spherical blur relative to their best correction. The mean (±1SE) reduction in vision is plotted in log units for each vision test. For each subject, the reduction in vision was computed by taking the difference between log scores under optimal conditions (best correction; monocular) and test conditions (spherical blur). Fig. 4 shows that 0.5 D of spherical blur reduced high and low contrast VA by only 0.1 log unit (one line of letters), but there was a larger, 0.3 log unit reduction on the SLCT--an average of three lines. As shown previously,[11] little effect was observed with the Pelli-Robson chart which uses large letters (low spatial frequencies) and is thus unaffected by small amounts of blur.

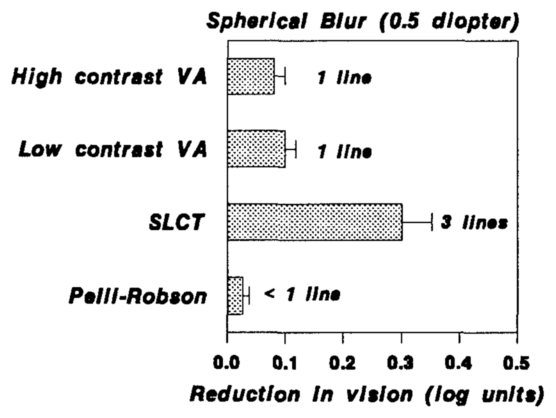

Figure 4. Mean (±1SE) reduction in vision to 0.5 D blur.

A similar, albeit larger, effect was observed with a small amount of astigmatic blur (+1 D x 90; Fig. 5). There was a 0.2 log unit (2-line) reduction in high and low contrast VA, but a greater, 0.55 log unit (5.5-line) reduction on the SLCT. As shown in Fig. 5, defocus had minimal impact on performance on the Pelli-Robson test.

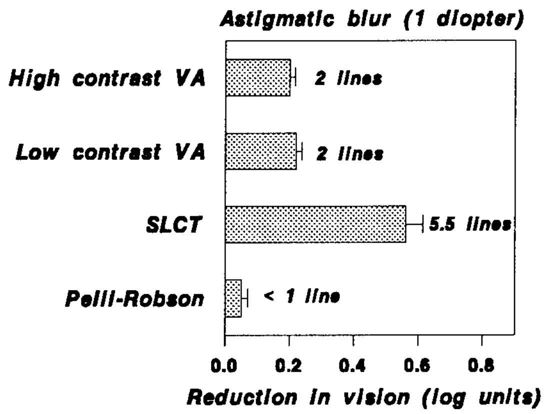

Figure 5. Mean (±1 SE) reduction in vision to astigmatic blur.

While defocus simulates effects of refractive error, a decrease in stimulus luminance can reduce vision, perhaps in a manner similar to that imposed by opacities of the ocular media. Fig. 6 shows that reducing luminance within the photopic range (from 100 to 6 cd/m^2) produced a 0.1 log (1-line) decrease in high contrast VA, a 2-line decrease in low contrast VA, a 1.3 line decrease on the Pelli-Robson chart, but a larger 5-line decrease on the SLCT.

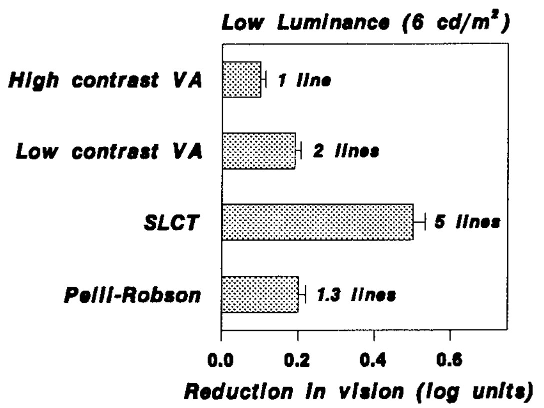

Figure 6. Mean reduction in vision when luminance was reduced from 100 to 6 cd/m.^{2}

As in previous studies,[12,13] vision with two eyes compared to one produced only a slight improvement in high and low contrast VA (two letters; Fig. 7), but a larger improvement in CS on the SLCT and Pelli-Robson tests (1.3 lines). Greater improvement on the Pelli-Robson test and SLCT indicate that conditions affecting binocular performance would be detected more readily by measuring CS rather than VA.

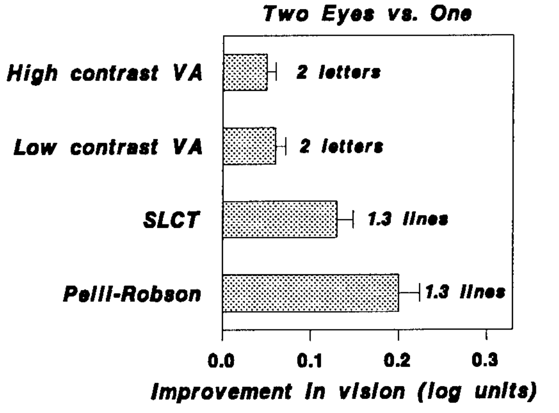

Figure 7. Mean improvement in vision with two eyes vs. one.

These results are summarized in Figure 8 which shows the mean (±1 SE) magnitude of the effect for each condition plotted for each test. On an absolute scale, the magnitude of the effects are largest for the Small Letter Contrast Test.

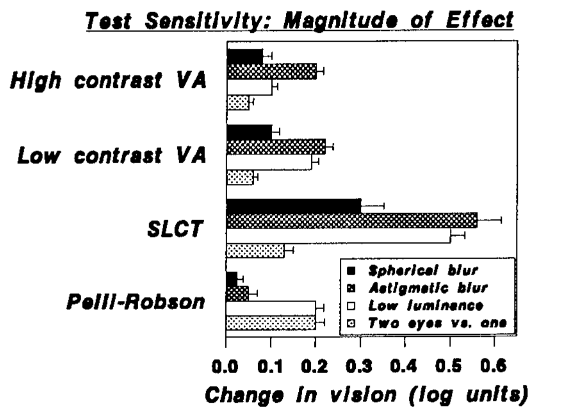

Figure 8. Mean magnitude of the effect for each condition is plotted for each test.

Test Sensitivity Relative to Variability

Results presented thus far suggest that the SLCT is more sensitive than standard letter chart tests to small amounts of blur, modest changes in stimulus luminance, and binocular enhancement. However, a larger effect does not ensure greater test sensitivity if variability also is greater. To standardize scores with respect to variability, the difference between each score and the value under optimal conditions was divided by the standard deviation of the measurement. This transformation, which quantifies all scores as standard deviations, allows for direct comparison between results of different tests. Figure 9 shows test sensitivity standardized relative to variability between (top) and within subjects (bottom). Values at the top represent the difference between each score and the mean under optimal conditions divided by the *group standard deviation,* while those at the bottom were computed from the difference between each individual's score and the

optimal score divided by the *within subject standard deviation.* Despite correction for variability, the SLCT still proved to be at least 2x more sensitive than standard tests.

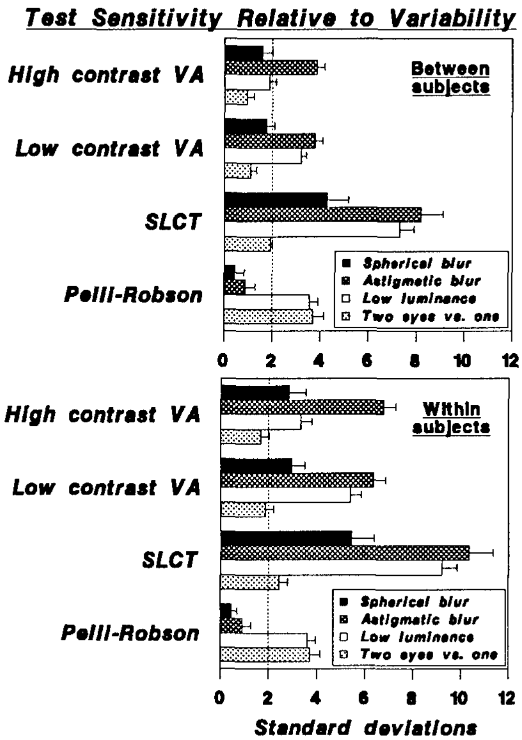

Figure 9. Test sensitivity is plotted as standard deviations for each test in each condition. Values are expressed relative to variability between (top) and within subjects (bottom).

Application In Clinical Conditions

Fig. 10 shows results for several clinical conditions characterized by subtle loss of vision. In each case the reduction in vision is plotted as standard deviations from the mean for normal subjects (n=21). In each condition, including early cataract, keratoconus, amblyopia, corneal infiltrates, and contact lens edema, the SLCT is more sensitive than standard vision tests for detecting subtle differences from normal.

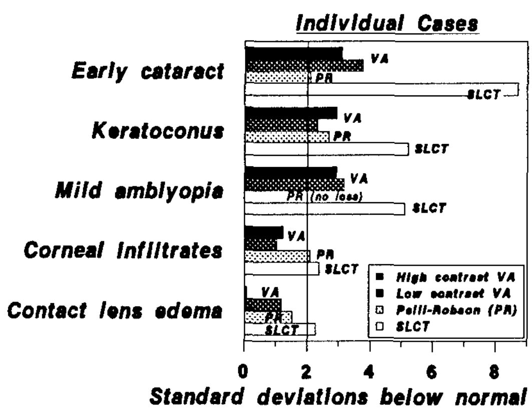

Figure 10. Test sensitivity in individual cases of visual loss.

Fig. 11 shows results from two patients, one with an early nuclear cataract in his right eye (top), and a second with mild amblyopia, also in the right eye (bottom). In each case, high contrast VA is shown at the top, and the difference between log scores of better eye and affected eye (LE - RE) is plotted for each test. In the case of cataract, there was a two-line difference in high and low contrast VA, and a one-line difference on the Pelli-Robson chart, but the difference between eyes on the SLCT was much greater--five lines. Perhaps if this patient had been tested earlier in the course of the cataract, then the only significant finding may have been on the SLCT. In the patient with amblyopia, there was less than one-line difference between eyes in high contrast VA, and 1.2 lines with low contrast VA, but a four-line difference between eyes on the SLCT underscoring the sensitivity of this test to subtle visual loss. The lack of any difference between eyes on the Pelli-Robson test suggests that the amblyopic deficit was limited to higher spatial frequencies.

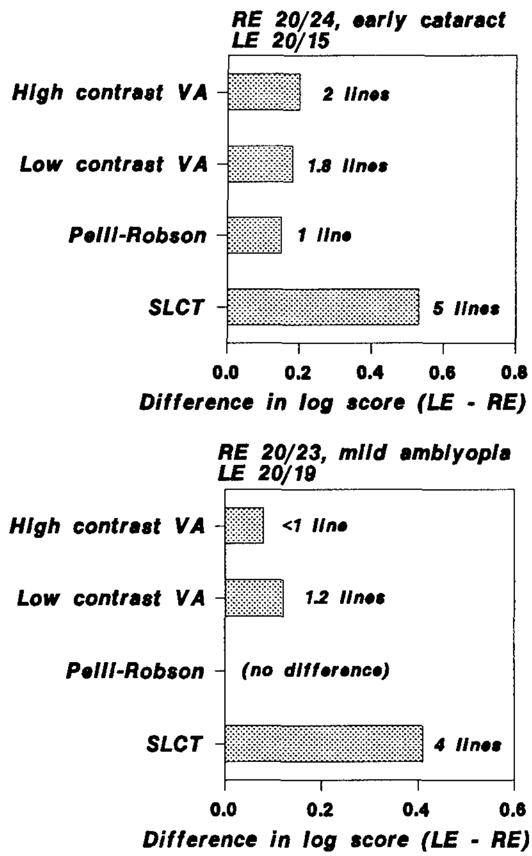

Figure 11. Two cases of subtle visual loss in one eye. The difference between log scores (good eye - affected eye) is plotted for a patient with early cataract (top) and for a patient with mild amblyopia (bottom).

Fig. 12 shows results for a senior aviator whose refractive error is shown in the upper right corner of the graph. The patient previously wore glasses, but recently switched to a monocular contact lens correction. He wears no lens in the

right eye, but a soft toric lens in the left eye to correct the greater degree of astigmatism. While the patient is pleased with his contact lens correction, and achieves visual acuities slightly better than 20/20, there is still an improvement with best spectacle correction compared to the habitual correction: no lens eye on right eye, soft lens on left eye. The improvement in vision, expressed as lines of letters on each chart, is plotted for each vision test. While best correction afforded only a 1-line improvement in conventional high contrast VA, there was a 2-3 line improvement on the SLCT. Such exacting information may be used to guide decisions as to whether or not pilots should be allowed to fly with contact lenses.

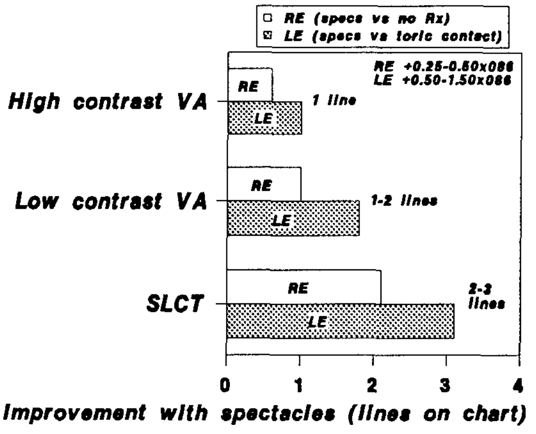

Figure 12. The improvement in vision with full spectacle correction as compared to the patient's habitual correction: no lens on right eye, soft toric contact lens on left eye.

DISCUSSION

Like other letter chart tests, the SLCT is easy to administer and easy to score. But despite its apparent simplicity, the SLCT offers an extremely sensitive approach for monitoring visual function. It uses a forced-choice, letter recognition task that is unaffected by shifts in patient criterion. Invaluable design principles conceived by Bailey and Lovie[5] and Pelli, Robson and Wilkins[8] are included and enhanced in the SLCT. By using an interval size of 0.1 log units and ten letters per line, a scoring precision of 0.01 log units per letter is achieved in the SLCT which is at least 2x finer than that found in existing tests. The unique feature of the SLCT, the use of small letters to measure CS, exploits the steep slope of the CS function where small changes in VA are associated with large changes in CS. This provides a sensitive index of visual resolution which complements existing tests of high and low contrast VA.

The present results confirm previous findings that small letter CS is more sensitive than VA to small amounts of blur, modest changes in stimulus luminance, and vision with two eyes compared to one.[1-4] These findings, initially demonstrated with letters generated on a computer monitor, were shown to be valid for the SLCT--a letter chart now available for general use. Previous results for spherical blur were confirmed and a similar effect was found with astigmatic blur. A modest reduction in luminance produced a small decrease in VA, but a larger decrease on the SLCT. This effect, which is not explicable by optical factors,[2] has been attributed to the quantal nature of light for which decreases in intensity are not matched by a proportional decreases in noise[14,15] Visual enhancement with two eyes compared to one was greater for CS than VA, a result also related to the steep slope of the CS function.[12,13] Most importantly, all results were validated statistically since greater sensitivity of small letter CS endured despite correction for variability.

Several clinical conditions, including early cataract, keratoconus, and mild amblyopia, were characterized by subtle losses of VA, but larger decreases on the SLCT. Since both VA and the SLCT use small letters composed of high spatial frequencies, and given the steep slope of the CS function, any condition that reduces VA should have a larger effect on the SLCT. The clinical cases described here exemplify this principle and underscore the sensitivity of the SLCT for detecting subtle visual loss. The SLCT should prove useful when there is loss of central vision undisclosed by standard tests. Applications include monitoring the course of vision in refractive surgery, macular edema, optic neuritis, cataracts, and evaluation of individuals for unique occupations such as aviation.

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In the conduct of research where humans are the subjects, the investigator adhered to the policies regarding the protection of human subjects as prescribed by 45 CFR 46 and 32 CFR 219 (Protection of Human Subjects).

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OPTIC NERVE HEAD DRUSEN: AN EXAMPLE OF AEROMEDICAL DECISIONS REGARDING VISUAL FIELD LOSS

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SUMMARY
Peripheral vision is a vital function which serves to alert the aviator to a potential target that may deserve closer attention. The confrontation technique for visual field testing is an invaluable tool for use by the flight surgeon to screen for defects without the need for bulky equipment. Yet this technique may miss field defects of potential aeromedical significance. Optic nerve drusen are known to cause progressive visual field disturbances. Formal visual field testing is necessary in order to properly evaluate an aviator with a condition such as optic nerve drusen. We reviewed our experience with 18 aviators at the Aerospace Consultation Service who received the diagnosis of drusen of the optic nerve. The influence of drusen on visual function and on the aeromedical waiver recommendation process is discussed in order to provide insight regarding appropriate aeromedical management.

ACRONYMS

ACS - Aeromedical Consultation Service
BVA - best corrected visual acuity
CT - computerized tomography
O.D. - oculus dexter
O.S. - oculus sinister
O.U. - oculi unitas
ONHD - optic nerve head drusen
PIP - Pseudoisochromatic Plates
S1 - sacral vertebra
USAF - United States Air Force
USAFSAM - United States Air Force School of Aerospace Medicine
VTA-DP - Visual Test Apparatus-Depth Perception

ONHD are not an uncommon finding on an ophthalmic examination. They were first described histologically by Muller (1) in 1858 and ophthalmologically by Liebreich (2) in 1868. Classically, they are referred to as hyaline bodies and represent accumulations of acellular, often calcified, material within the optic nerve (3). These accumulations have histologically always been found anterior to the lamina cribrosa. Interestingly, however, they tend to remain beneath the surface of the optic nerve head, or "buried" early in life, with a tendency to become visible later in life. They are inherited as an irregular autosomal dominant trait with a prevalence of 3.4 per 1,000, whereas autopsy series give a prevalence of 0.4-2.0%. The exact origin of the material deposited remains an enigma, but ultrastructural studies reveal extruded calcified mitochondria from altered axonal metabolism and transport mechanisms (4). Although they usually remain clinically asymptomatic, their clinical hallmark is progressive visual field disturbances, although the potential for transient obscurations of vision in many cases precipitates their discovery (5,6). The clinical dilemma evolves from their associated disturbance in the appearance of the optic nerve architecture such that they can cause elevation and blurring of the optic disc margin, so-called pseudopapilledema, which must be differentiated from true papilledema (optic disc swelling secondary to elevated intracranial pressure). Diagnostic tests used to help identify hyaline bodies within the optic nerve include fluorescein angiography, red-free photography, indirect ophthalmoscopy, CT scan, and ophthalmic ultrasound. Their ability to

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autofluoresce when excited with a cobalt blue filter has often facilitated their identification on indirect ophthalmoscopy.

Aeromedical concerns evolve around the differential diagnosis of abnormal-appearing optic discs and the visual disturbances that can occur in association with ONHD. Transient disturbances in both the central acuity and visual fields have been documented in association with ONHD. In some cases, such phenomena have occurred intermittently over decades (6). Although the typical drusen-induced obscuration in vision may last seconds to hours, there have also been more prolonged losses of function lasting days. In addition, the association of drusen with spontaneous hemorrhages in and around the disc may also result in acute and abrupt changes in visual function. Clinically, the main concern is their high probability to induce slowly progressive loss of peripheral visual field either from encroachment directly on the optic nerve or compromise of the optic nerve vascular supply. As high as 87% of individuals with ONHD can be expected to have visual field abnormalities (3), the majority of which will progress slowly over time. Once the clinical diagnosis of drusen is established aeromedically, the peripheral visual field function must be assessed to ensure adequate visual fields that are consistent with mission effectiveness and flying safety. Since drusen-related optic nerve problems are usually asymptomatic, a routine continued surveillance program to assess visual function in aircrew with ONHD is appropriate.

SUBJECTS

The Ophthalmology Branch of the ACS, formerly USAF SAM, acts as a medical consultant to the USAF Surgeon General concerning USAF aviators who have aeromedically disqualifying eye diseases or abnormalities. Since 1968, 18 aircrew with ONHD received complete eye exams at the ACS. Their ages at the time of initial diagnosis ranged from 9 to 56 years old. Their military flying experience ranged from 0 hours in 2 undergraduate pilot students to approximately 9,000 hours. None have been involved in any aircraft mishaps.

RESULTS

Of the 18 aviators with ONHD, 2 (11%) were diagnosed prior to actual flying training; the majority (89%) were discovered after training. Of note, 9/18 (50%) of the evaluees were diagnosed with ONHD during routine evaluations at the ACS Ophthalmology Branch. None of the 18 had a family history of ONHD and only 1/18 (6%) had symptoms (noticed a peripheral blind spot) at the time of diagnosis. Seventeen of the eighteen presented with BVA of 20/20 or better O.U. One of the aviators with bilateral ONHD had an initial BVA of 20/15 O.D. and 20/25 O.S., but was subsequently corrected to 20/15 O.U. on follow-up evaluations.

Initial visual field testing was performed on 12/18 (67%) of the evaluees and defects were present in 7/12 (58%) of the cases. Subsequent visual field testing revealed changes overall to be present in 10/14 (71%). These field changes included: 1) enlarged blind spot (4), 2) nasal step (3), 3) sectoral defects (3), 4) nasal scotoma (3), and 5) field constriction (1). Progressive visual field changes were noted in five of the evaluees. Four of fifteen tested were found to have an afferent pupillary defect. Color vision testing using PIP was normal in all eighteen. Depth perception/stereopsis by VTA-DP was normal in 17/18 of the evaluees. The one evaluee who failed the VTA-DP passed the Verhoeff and was identified to have coincident microtropia. ONHD were binocular in 11/18 (61%), while four had drusen present only in O.D. and three only in O.S. The majority of evaluees (15/18; 83%) had cup/disc ratios of less than 0.3, reflecting the so-called "crowded" disc. Spina bifida occulta at S1 was found in 6/18 (33%), while congenital lower spine abnormalities were present in 9/18 (50%).

DISCUSSION

Anomalous elevation of the optic disc (pseudopapilledema) may closely resemble and must be distinguished from true optic disc swelling. There are, however, several distinguishing ophthalmoscopic differences that can help identify pseudopapilledema, including 1) absence of disc hyperemia; 2) surface arteries are not obscured; 3) physiologic cup is often absent; 4) subnormal size disc; 5) abnormal disc vascular patterns are often present (3,7,8); 6) elevation is confined to the disc (9); 7) irregular and moth-eaten disc border appearance (10); and 8) round/slightly irregular excrescences on the disc.

Visual field defects with ONHD are a common finding. Four large reviews reported an incidence of visual field defects in 237 of 298 eyes (80%), with a range of 51-87% (3,11,12,13). These reported defects included lower nasal, sector and arcuate defects, enlarged blind spots and concentric constriction (12,13). Despite failure to obtain visual fields in four of our early cases, visual field defects were noted in

at least 71% of cases. These changes progressed in at least 36% of the aviators tested. These results were consistent with other drusen population studies.

Although slowly progressive visual field defects are common, disruption of BVA, color vision and stereopsis rarely occur. Associated defects in any of these three other categories should suggest an etiology other than ONHD. Our study group correlated well with those previously reported in this regard (3,8,18). Furthermore, ONHD are usually a bilateral process (3,8,18) which occurred in 61% of our cases.

One of the 18 patients was found to have pseudoxanthoma elastica with angioid streaks. This condition, as well as other retinal degenerations, has been reported as a relatively frequent association with ONHD (9,14,15, 16,17). In addition, spina bifida occulta was identified in 33% and other lower spine changes in 50%. Though this is a small series, this is higher than the reported 20% rate of spina bifida within the normal population (19).

Overall, 17/18 (94%) aviators were recommended by the Ophthalmology Branch for flying duty waivers for ophthalmic diagnoses alone, with 15/17 (86%) receiving recommendations for Flying Class II (unrestricted) duties. Only one evaluee, an undergraduate pilot trainee, did not receive a waiver recommendation. This evaluee had a new-onset afferent pupillary defect and had a significant inferonasal visual field defect O.S. under monocular viewing conditions which was believed to be inconsistent with flying training. One of the 17 was a refueling boom operator and received a Flying Class III (not in primary control of aircraft) waiver recommendation. One received a Flying Class IIC (restricted to aircraft whose mission does not require monocular devices/techniques) waiver recommendation due to monofixation syndrome.

Five of the 18 (28%) actually received official disqualifications. Three of these five were disqualified because of other coexistent nonocular diseases, one for administrative reasons, and only one because of ONHD. Thirteen of the 18 (72%) received official waivers to fly, including three who were assigned to high-performance aircraft. Two of the 13 received limited restriction waivers.

Current USAF policy regards the following visual field defects to be disqualifying: 1) Contraction of the normal visual field in either eye of 15 degrees or more in any meridian; 2) any scotoma which is due to an active pathological process; and 3) any scotoma that is the result of a healed lesion, unless the resulting deficit does not compromise flying safety or mission completion (20). However, each individual case is reviewed for the reason and extent of the defect, binocular visual field coverage, its impact on the categorical type of aircraft being flown, and risk/rate of progression.

SUMMARY

ONHD can be an elusive and confusing etiological cause of transient loss of vision. They do not cause disturbances in central vision, color perception, or stereopsis. They do, however, commonly cause progressive permanent peripheral vision disturbances in a high percentage of cases. Despite the slowly progressive nature of the visual field loss associated with ONHD, the USAF experience has shown that ONHD can be compatible with continuation of an aviator's career, provided acceptable levels of visual field function are maintained. Our current recommendation is that aircrew may be considered for waiver to resume flying duties providing the binocular visual field is adequately preserved so as not to compromise functional integration in the aircraft. However, an integral part of the decision to return to an aircrew member to any cockpit should be a commitment to a routine and regular surveillance program, which will ensure that the visual fields remain within safe and waiverably acceptable limits.

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TRANSIENT VISION LOSS IN AIRCREW

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SUMMARY
Etiologic factors that can result in transient disruptions in vision comprise an extensive differential diagnosis and include both central nervous system and systemic causes. Aircrew are not immune to the majority of these etiologies and their vulnerability expands as they extend their flying careers. Furthermore, the aviation environment may introduce additional predisposing factors. This paper concentrates on those etiologies that are felt to be the most common or unique clinical entities potentially responsible for transient visual changes in aircrew and highlights specialized cases that relate directly to the aerospace environment, such as altitude-related phenomena. Management and disposition of aircrew with these problems oftentimes presents a unique occupational dilemma. When applicable, the USAF ACS's experience with specific diagnoses related to transient visual loss or transient visual disturbances in aircrew is discussed.

ACRONYMS
ACS - Aeromedical Consultation Service
BRVO - branch retinal vein occlusion
CNS - central nervous system
CRVO - central retinal vein occlusion
G - gravitoinertial force
$+G_z$ - positive (footward) gravitoinertial force
HCL - hard contact lens(es)
ICSC - idiopathic central serous chorioretinopathy
ION - idiopathic optic neuritis
IOP - intraocular pressure
M-1/L-1 - anti-G straining maneuvers
m - meters
mg - milligrams
mm - millimeters
mmH_2O - millimeters of water
MRI - magnetic resonance imaging
MS - multiple sclerosis
NLP - no light perception
OND - optic nerve drusen
ON - optic neuritis
PG - pigmentary glaucoma
PLZT - lead, lanthanum, zirconate titanate
PTON - post-traumatic optic neuropathy
TVL - transient visual loss
TVO - transient visual obscuration
USAF - United States Air Force
VF - visual fields

INTRODUCTION
Traditionally, TVL is a reversible visual deficit lasting less than 24 hours and is usually limited to discrete events such as an abrupt loss of all or a portion of vision in either one or both eyes (1). Brief episodes lasting less than 10 minutes are often classically called amaurosis fugax, but in some cases, this term is used for longer events such as a reported case lasting 7 1/2 hours (2). For the purposes of this paper, TVL will be extended up to several days of visual disturbance, so that a broader group of aeromedically significant etiologies (i.e., OND) may be discussed. Furthermore, this paper will also consider TVO in the discussion, as any transient distortion of vision (i.e., diplopia, scintillations) can potentially have a detrimental impact in the aircrew environment.

The majority of cases of TVL in patients less than 40-45 years of age largely goes unexplained. Although migraine and cardioembolism are often diagnosed, most events are benign and probably due to vasospasm (1,3). In patients over 40 years of age, the vast majority of TVL episodes are attributed to atheromatous thromboemboli (1). Although aircrew may remain on flight status well into their sixties, the majority are between 20 and 50 years old. Thus, a comprehensive differential diagnosis for TVL/TVO is appropriate in this paper (Table 1). Aircrew are not immune from these etiologies and may, in fact, even be at greater risk due to hazards and reduced thresholds. However, operationally, we will address only

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the most aeromedically relevant etiologies (Table 2) in aircrew and the aerospace environment. If we approach possible TVL based on their proposed mechanism, we can utilize a recently reported classification based on 850 cases of amaurosis fugax between 1971 and 1987 (4), which is as follows: Type 1 - transient retinal ischemia (embolic); Type 2 - retinal vascular insufficiency (hypoperfusion); Type 3 - angiospasm; and Type 4 - idiopathic (associations with myopia, drusen, and migraines).

CARDIOVASCULAR DISORDERS

Ischemia produces TVL by temporary vascular occlusion or reduced blood flow through nonocular vessels. TVL may result from temporary vascular occlusion via three known mechanisms: thromboembolism, vasospasm, and/or compression. In thromboembolism, the circulation to the eye or visual cortex may be temporarily blocked by an embolus originating from a diseased vessel, cardiac valve, or from injection of particulate matter (1). The embolic theory establishes that emboli from extracranial vessels are responsible, but this theory does not adequately explain several clinical facts, such as emboli not being observed in the retinal vessels during monocular TVL attacks. Monocular blurred vision must be investigated, since its origin is so commonly due to atherosclerosis of the carotid system (5). Since it is well known that a substantial number of patients with TVL do not have atheromatous disease, other possible mechanisms must be considered (Table 3) (6).

Vasospasm was formerly invoked as the most likely mechanism for TVL, but now is implicated only in hypertensive crisis, subarachnoid hemorrhage, and migraine (1). Vasospasm is characterized by the sudden onset of total visual loss or progressive contraction of the VF, sparing fixation (7). Direct observations of the fundus during such attacks have revealed narrowing of the retinal arteries and veins, cessation of blood flow, segmentation of blood columns, and optic disc pallor. Many of these patients have known migraine diathesis and it is postulated that the vast majority of these patients are experiencing a migraine equivalent (6).

A relatively rare cause of TVL is external compression of blood vessels that nourish the visual pathway. This occurs in papilledema, in which pressure on the vessels in the swollen nerve head causes blackout of vision over the entire field of one or both eyes lasting 1-2 seconds (changing obscurations of vision) (8). These episodes are so brief that the patient is apt to ignore them at first.

They may be precipitated by standing up or by the Valsalva maneuver. Fundus examination shows markedly swollen discs and the intracranial pressure is generally above 200 mmH_2O. Normalization of the pressure eliminates the symptom, although disc swelling may take weeks to resolve (1).

Compression of a part of the visual pathway or its blood supply by a tumor generally causes slowly progressive visual loss, but may rarely produce TVL as well. For example, an intraorbital tumor may intermittently compress the optic nerve as the eye rotates into eccentric gaze positions (9).

Transient disturbances have been reported in association with arrhythmias, carotid artery disease, myxoma, and mitral valve prolapse, and as a part of the vasovagal complex.

HYPOXIA

TVL occurs with hypoxia; there is probably a microscopic decrease in visual capability on every flight to altitude. Vision is the first special sense to be altered by hypoxia, as evidenced by diminished night vision. From sea level to about 3,000 m, known as the indifferent zone, there is probably a very slight impairment in night vision. From 3,000 to 5,000 m is the zone of adaptation; at 5,000 m, there is a loss of approximately 40% in scotopic vision. Between 5,000 and 8,000 m is the zone of inadequate compensation, so called because the physiologic processes can no longer compensate for the lack of oxygen. Here, the scotopic visual disturbances become more severe. Above 8,000 m is the zone of decompensation or lethal altitude. Circulatory collapse will occur, with loss of vision, both photopic and scotopic, and loss of consciousness. All of the above-mentioned effects on the visual apparatus are reversible with oxygen or return to ground level.

GRAVITY

In flight, aviators encounter a number of gravitational forces such as linear acceleration, as in catapult takeoffs, aircraft carrier landings, ditching, and high-speed bailout; radial acceleration encountered in banks, turns and pullouts from dives, loops, and rolls; and angular acceleration which occurs in spins, storms, and tumbling following bailout from aircraft. It is the $+G_z$ acceleration that mainly concerns pilots

of high-performance aircraft. When $+G_z$ increases, the quantity of blood returning to the heart is diminished and the heart continues to beat, but diminution of the volume of systolic blood reduces cardiac output, lowers arterial tension, and causes a drop in pressure. When the arterial pressure in the ophthalmic artery no longer exceeds the IOP, visual function becomes impaired. Grayout is first noted and, finally, blackout may ensue. On average, a pilot begins to lose peripheral vision at $+3.5\ G_z$ to $+4.5\ G_z$; blackout or complete loss of vision occurs at $+4.0\ G_z$ to $+5.5\ G_z$. However, these numbers are not absolute, since the blackout depends on the rapidity of onset of the G forces and physical condition of the aviator. More importantly, clothing has been designed to enable the aviator to reach higher G forces and maintain his efficiency for longer periods of time. This and other factors such as improved physical conditioning, muscle tension, performing maneuvers such as the M-1 or L-1, reclining or tilting seats, and positive pressure breathing will all increase the amount of $+G_z$ tolerance before loss of vision. With a reduction in the G force, the aviator's vision returns; however, there may be a period of confusion following this, so that the vision will not be instantaneously useful.

VALSALVA MANEUVER

The Valsalva maneuver, i.e., raising the intrathoracic or intraabdominal pressure against a closed glottis, may occur such as in coughing, vomiting, lifting, straining at stool, in wind-blast injuries, and in performing anti-G type maneuvers. This type of maneuver may cause a venous vasculopathy. Such a venous pressure elevation, particularly if sudden, may produce subconjunctival hemorrhages, head/neck skin petechiae, retinal hemorrhages, or exudates. A recently reported variant of this Valsalva type retinal injury is sudden visual loss associated with sexual activity (10). This type of retinopathy was classified by Duane in his article, "Valsalva Hemorrhagic Retinopathy" (11), as:

a. Mild - retinal edema
b. Moderate - superficial transudates ("fluffy clouds")
c. Severe - preretinal hemorrhages (Valsalva hemorrhagic retinopathy)

TVL following this condition may be minuscule if peripheral, or rather disastrous if located in the macular area and could last months before any recovery occurs. Hypothetically, extreme straining on the Valsalva maneuver could raise the intraocular pressure to such an extent as to impede the arterial flow into the eye. Under these conditions, there could be a dimming or loss of vision, since this would, in effect, be acting like G forces act on the peripheral blood vessels, causing grayout and then blackout. This would necessitate an extremely large increase in the intraocular pressure as a result of the Valsalva maneuver or, if the perfusion pressure at the ophthalmic artery was already low, this might occur more easily. Recovery of the vision should be almost instantaneous following relief of this pressure.

FLASH BLINDNESS

Exceedingly bright lights can produce physiologic alteration and/or damage that may either be permanent (retinal burn) or reversible (flash blindness) after variable amounts of time. In some cases, flash blindness may induce irreversible cellular damage. The damage caused is a function of the intensity, wavelength, location and duration of the light source, as well as the individual's age. The eye is more susceptible to long-range injury from nuclear flash or lasers at far greater distances than any other organ or tissue of the body. The potential danger of flash blindness and chorioretinal burns from thermonuclear weapons has now dramatically decreased. During daylight, with high ambient illumination and a small pupil, the retinal burn and flash blindness problem is greatly diminished. At night, with a large pupil, protection is an absolute must. Direct unprotected viewing of a thermonuclear explosion would undoubtedly result in permanent retinal injury. However, if one were only flash-blinded, then there would be a period of time, e.g., anywhere from 10 to 30 seconds, depending on the intensity of the flash, in which the vision would be below that needed for flying. Protective filters and goggles, the most recent of which consist of PLZT material, have been developed to reduce this threat for the aviator. With a reduction in the possibility of nuclear flash blindness, there has been a concomitant proliferation of the laser threat. A laser may cause a permanent lesion or simply act as a bright light, causing a temporary decrease in vision with full recovery after a number of seconds. Although laser protective filters and goggles have been developed, agile laser threats make it exceedingly difficult for protective devices to completely protect from this threat without disrupting other aspects of visual function.

In its more benign form, "flying into the sun" or inadvertent glances at the sun occurs routinely and

full visual recovery usually occurs in a matter of seconds.

DECOMPRESSION SICKNESS (BENDS)

In decompression sickness, bubbles can form in many parts of the body. Certain target organs seem affected more readily. The effects on these anatomic locations account for the signs and symptoms seen in the bends. Signs and symptoms referable to the CNS give us neurologic decompression sickness. CNS involvement occurs in less than 10% of the cases of decompression sickness. Neurologic decompression sickness presents in two forms: a spinal cord and a brain form. TVL will only occur in the brain form and is usually associated with spotty sensory and motor signs and symptoms that cannot be attributed to a single brain locus. This can be manifested by headache, at times of a migrainous nature, and visual disturbances consisting of scotomas, tunnel vision, diplopia and blurring. Visual symptoms will usually improve upon reducing the altitude and/or administering 100% oxygen.

MIGRAINE

Migraine can be placed into three basic groups: common, classic, and complicated. Common migraine is characterized by headache, more or less severe, with nausea and vomiting. Resolution of this type of headache takes a fairly long time, 3-24 hours. Classic migraine is less common and has a classic aura or focal neurological deficit before or during the headache. The aura may involve motor or speech deficits, but is usually visual in nature. Complicated migraine refers to ophthalmologic (retinal), hemiplegic, basilar artery, acephalgic, and cluster forms of migraine. The most common type in aircrew is the acephalgic migraine, since the more severe types are most likely incompatible with a flying career. Acephalgic migraine, with only visual symptomatology, is not uncommon. A review of 61 active USAF flyers over a period of 15 years revealed that the number of acephalgic spells varied from 1 to 100, most lasting 15-30 minutes, and were present for 2 weeks to 25 years (12). The ocular involvement included transient hemianopia, bilateral central scotoma, altitudinal field loss, and tunnel vision, but bilateral fortification scintillations were the most common visual event. Only two manifested a headache severe enough to affect their flying. The authors made some generalizations concerning acephalgic migraine: 1) it is common; 2) it is most commonly seen by the ophthalmologist; 3) it can occur at any age; 4) occurrence with other transient neurological involvement is not rare; 5) there is a positive family history only 25% of the time; 6) it cannot be diagnosed unless micro-embolism and epilepsy have been reasonably excluded; and 7) it should be considered in any acute episodic neurologic disorder.

OPTIC NEURITIS

A pathological process that disrupts transmission of neural information in one or both optic nerves can be regarded as ON. It has an extensive differential diagnosis, to include both primary and secondary causes. An initial episode of ON for which no specific etiological cause is found is referred to as primary ION. The critical aeromedical concerns with ION are its impact on visual performance, both transiently and residually, and its prognostic association with MS. ION is usually characterized by a transient decrease in central or peripheral vision that can be as profound as NLP in the affected eye. This visual loss progresses to its clinical nadir by seven days. ION generally affects 20- to 50-year-olds. Any individual who has further visual loss beyond seven days or is outside this age range must be strongly suspected to have a process other than primary ION and should be thoroughly evaluated for other causes. Associated features of ION include acute disturbances in central or peripheral vision, stereopsis, and color vision; afferent pupillary defects; diplopia; headaches; and painful eye movements. Hot ambient temperatures in the cockpit may precipitate TVL or other neurological dysfunction by elevating the body temperature, referred to as Uhthoff's phenomenon. This symptomatology should raise the clinical suspicion of MS.

The international literature lists the risks to develop MS following an initial episode of ION to be between 11.5% and 85% (13,14). However, many of these articles are biased either by geography, selection criteria, sex, or other factors that do not directly correlate to a predominantly male aircrew population. The overall risk in males is generally regarded to be 20-30%. The Optic Neuritis Treatment Trial (15) identified the risk as 19% overall, but recognized a 3-fold increased risk of developing MS in females over males who present with ION.

The ACS experience to date with 30 aircrew members who presented with primary ION revealed that 30% developed MS. In those individuals who did not appear suspicious for MS and who recovered either normal or near-normal visual capacity, the USAF was able to reinstate 57% back into the cockpit with waivers.

The current literature supports the premise that neither a recurrent episode nor a bilateral presentation of ION is associated with any greater risk of MS. The risk of MS is much lower after 5 years following the initial episode of ION and, in general, MS patients who present with ION have a more benign course. Similarly, the severity of the visual acuity loss associated with an episode of ION does not correlate with the amount of anticipated recovery, as there have been cases of NLP eyes that have fully recovered to 20/20. Subtle post-ION differences in visual performance in the affected eye usually remain, both subjectively and objectively.

Current USAF policy prohibits entry into flying with a history of ION. However, trained aircrew who experience an episode of ION, recover normal or near-normal waiverable visual function, manifest a normal MRI, and have no other clinical features that raise the specter of MS, may be returned to the cockpit with waiver. Frequent re-evaluation for neurological and ophthalmological stability is required.

TRAUMA

Several mechanisms explain TVL associated with trauma, but one of the most intriguing, albeit uncommon, is "posterior indirect optic neuropathy" or PTON. This condition usually occurs after a blow to the ipsilateral forehead, with or without loss of consciousness (16). The degree of optic nerve injury correlates poorly with the degree of consciousness lost or with other neurologic deficits. Perhaps the position, rather than the degree of impact, is the critical determinant (17). Clinically, visual acuity loss, which may be mild or profound, is accompanied by nerve fiber bundle VF defects and afferent pupillary defect, but usually no ophthalmoscopic abnormalities occur. The usual site of injury, confirmed by autopsy (16), is the intracanalicular optic nerve, which shows evidence of infarction. The current belief is that the intracanalicular nerve is vulnerable because it is tightly adherent to the periosteum, lies in a crowded, nondistensible space, and has a fragile pial circulation, especially in its superior portion. Presumably, shearing forces cause edema as well as tears and collapsed vessels, and infarction occurs secondarily. The contribution of hematomas and fractures is uncertain. PTON occurs predominantly in young males of all ages. A recent review of 33 civilian cases (18) identifies the commonest mode of injury to be a fall from a bicycle, closely followed by an automobile accident.

Another uncommon but interesting condition secondary to trauma is "post-traumatic transient cortical blindness." It is defined as a reversible complete visual loss associated with normal pupils and funduscopy without neurological sequelae following minor head trauma. It can persist for hours. The onset of the blindness after injury may be delayed minutes to hours (19). The true incidence of the syndrome is unknown, but the largest retrospective series reported an incidence of 0.6% among all head injuries seen in an emergency room (20). The pathophysiology of the syndrome remains obscure. Clinically, symptoms include those commonly associated with relatively minor occipital head trauma. Many investigators suggest that trauma-induced cerebrovascular vasospasm, similar to that observed in migraine, causes the transitory blindness. The differential diagnoses for cortical blindness also include stroke, cardiac arrest, hemorrhagic shock, meningitis, uremia, vertebral angiography, cardiac surgery, and carbon monoxide poisoning (19), although strokes and cardiac arrest predominate in adults (21).

OPTIC NERVE DRUSEN

OND are acellular, laminated, often calcified concretions in the optic nerve. Although the exact source of these deposits is unknown, ultrastructural studies suggest altered axonal metabolism and transport mechanisms that result in the extrusion of calcified mitochondria. These deposits, or hyaline bodies, can slowly enlarge and, although usually buried within the nerve head early in life, often become visible at the surface of the optic disc later in life. They are inherited as an irregular autosomal dominant trait with a distinct predilection in Caucasians. Their clinical prevalence is 3.4/1,000, and autopsy prevalence is 0.4-2.0%. They affect both sexes equally and are usually observed in the second or third decade of life as a silent exam finding. Enlargement of the deposits encroaches on and may disrupt nerve function. Although they usually spare central visual acuity, slowly progressive peripheral VF loss is their hallmark, occurring in as many as 87% of patients (22). They may also become symptomatic from a spontaneous hemorrhage or ischemic infarction of the optic disc. Because they elevate and obscure the optic disc (pseudopapilledema), they are often confused with true papilledema and must be differentiated from other pathological causes of disc elevation.

OND can cause TVL lasting from seconds to hours which may be profound during the attack (23). These occurrences may be indistinguishable from TVO associated with true papilledema and are believed to be the result of transient ischemia. The combination of TVO and abnormal optic discs requires complete ophthalmologic evaluation.

The USAF has followed 18 aviators with OND. Only one aviator noted symptomatology related to the drusen prior to diagnosis and 89% were diagnosed after flying training. At least 71% had associated VF abnormalities and no cases reported TVO. Progression of the VF defects were apparent in 29% of the aircrew. Current USAF policy permits continuation of flying with waiver for OND, providing the VF defects do not represent a significant compromise in binocular function. Since OND may enlarge, it is imperative that periodic VF be performed to monitor the process.

BAROSINUS PNEUMOCELE

A pneumocele of a paranasal sinus is defined as an aerated sinus lined with normal epithelium that can pathologically expand due to lost integrity of the bony sinus wall. Sinus wall integrity can be compromised by surgery, trauma, tumor, or infection. In some cases, there may be a congenital absence or dehiscence in part of the bony wall. Autopsy series reveal sphenoid sinus defects exposing the optic nerve in 4% of cadavers, with another 4% exposing the carotid arteries (24). Pneumoceles can enlarge acutely beyond the sinus cavity and cause TVL when the pressure within the sinus exceeds ambient pressure. This may occur from nose blowing, sneezing, Valsalva maneuver, or paranasal sinus blockage in association with reduced atmospheric pressure such as increasing altitude, any of which can induce TVL. Changes in central or peripheral acuities or alteration in neuromuscular function of the eye, i.e., ptosis or diplopia, may occur. This type of pneumocele is called barosinus pneumocele (25). It is differentiated from pneumosinus dilatans, which is an abnormally enlarged sinus with intact bony walls and no acute alterations with changing pressure, although with potential to encroach on adjacent structures and also compromise visual function (26).

Case report (25): A 41-year-old male pilot/physician with 2,000 military flying hours experienced 1- to 2-minute alterations in his left unilateral VF when climbing through 7,000 feet cabin altitude which abated after a painless sensation of "air release" occurred "somewhere" in his left sinuses. One ground episode occurred when he blew his nose. Clinical evaluation revealed an enlarged sphenoid sinus, an aerated posterior clinoid process, lateral bony dehiscence of his left optic canal within the sphenoid sinus, and a soft tissue mass (polyp) that was intermittently blocking the sphenoid sinus ostia. Surgical removal of the polyp, enlargement of the sphenoid ostium, and a partial left ethmoidectomy resulted in complete resolution of the symptoms, with over 100 uneventful post-operative sorties since he returned to flying duties.

Other cases are reported in the literature involving a similar sphenoid sinus relationship to visual loss in airline passengers (27,28).

GLAUCOMA

Classically, visual loss due to glaucoma is manifested by very slow, very gradual nerve fiber bundle type of visual defects. However, transient monocular visual loss (seconds) from glaucoma has been reported. Sharp rises in IOP more typically occur in narrow-angle glaucoma (29), which causes corneal edema and blurred vision, usually monocular. This is rare in aircrew, since a 30-year record survey at the ACS showed that only 3 aviators were diagnosed with narrow-angle glaucoma, whereas over 600 evaluees had a diagnosis of open-angle glaucoma or intraocular hypertension. Aviators are more apt to have a sudden increase in IOP as a result of a pigmentary type of disturbance, such as pigmentary dispersion syndrome or PG. Sudden increases in IOP have been noted in individuals with PG, such as following extreme exercise, and this could act in a similar fashion to an attack of narrow-angle glaucoma. Therefore, the possibility, although rare, is there for TVL due to an abrupt increase in IOP due to PG.

PAPILLEDEMA

Papilledema is defined as swelling of the optic nerve head secondary to elevated intracranial pressure (23). Loss of vision over seconds can occur due to brief fluctuations in intracranial or systemic blood pressure. Furthermore, other causes of disc elevation (pseudo-papilledema) may also result in TVO/TVL, which are typically painless and fleeting (30,31,32). They occur over seconds and are often related to postural changes (30,33,34). Sadun et al. (23) presented case reports of TVO/TVL in four patients with elevated optic discs not secondary to elevated intracranial pressure. The etiologies included vitritis, optic nerve sheath meningioma, Fuch's coloboma, and intrapapillary drusen. Persons with such pathology involving disc

elevation, when exposed to brief fluctuations in intracranial or systemic blood pressure from G or G-related maneuvers, may be further predisposed for transient loss of function in the eyes.

IDIOPATHIC CENTRAL SEROUS CHORIORETINOPATHY

ICSC is a focal serous detachment of the sensory retina (neuroepithelium) due to altered barrier or pumping functions at the level of the retinal pigment epithelium (35,36). Stress has been implicated but not conclusively proven to be an etiologic factor in ICSC (37). It typically occurs in 30- to 40-year-old healthy males and may be totally asymptomatic unless the central macula is affected (37). It affects males more commonly than females in ranges of 2:1 to 7:1 (38). Subjects may complain of mildly decreased, blurred or distorted vision, decreased color perception, and defective stereopsis. It is bilateral in 2-30% of patients and recurrence is common (40%). The serous detachment often undergoes spontaneous resorption of the fluid with visual recovery within 1-6 months after onset, although mild metamorphopsia, faint scotomas, abnormalities in contrast sensitivity and stereopsis, and mild color vision defects may persist.

A 1988 review of resolved ICSC in 55 eyes (47 USAF aviators) revealed that 86% attained a final visual acuity of 20/20 or better, 90% had normal stereopsis on final examination, 87% had normal color vision, and 49% had normal central VF (38). The visual and aeromedical prognosis from a single attack of ICSC is generally favorable, but repeat attacks can further jeopardize flying status (38). Such aircrew must be regularly monitored for disturbances in visual function. Overall, 97% of the flyers were eventually restored to the cockpit.

KERATOCONUS

Keratoconus is a noninflammatory disorder characterized by central thinning and protrusion of the cornea (39), usually beginning in adolescence or early adulthood. Although associated with several structural and biochemical abnormalities, the precise etiology is unknown and no treatment has influenced its rate of progression (40). It frequently leads to a decreased visual function, occasionally severe enough to require corneal transplantation. Early keratoconus may be corrected with spectacles, but typically require rigid contact lenses (41). Keratoconus may cause TVL because of induced optical effects that require frequent optical correction changes. Advanced cases may acutely develop corneal edema (acute hydrops) over several hours from a Descemet's membrane tear (42). These tears usually heal spontaneously in 6-10 weeks. The corneal edema then disappears, but stromal scarring may develop.

The USAF experience reveals that 83% of trained flyers with keratoconus returned to flying after appropriate optical correction of their best corrected visual acuity. However, they require frequent follow-up and optical correction changes.

DRUGS

Various medications, drugs, and toxins have been attributed to cause various visual changes induced by a variety of mechanisms. For example, acute medication-induced blurred vision has been reported in the literature from diuretics, anxiolytics, and oral hypoglycemics. The diuretics are felt to possibly interfere with the ion/fluid exchange between the aqueous humor and the lens. The anxiolytics may cause visual changes from central interference with extraocular muscle movements, as these medications possess central muscle relaxant properties. The oral hypoglycemics can cause blurred vision due to hypoglycemia, which can induce lens changes (43).

Several medications are known to alter the refractive status of the eye, usually by causing ciliary muscle spasm or increasing the refractive power of the lens. Cholinergic stimulating drugs, such as pilocarpine or carbachol, induce myopia by producing ciliary muscle spasm (44). Recovery from ciliary muscle spasm usually takes 3-4 hours (45). Topical steroids may induce acute corneal changes secondary to elevation of IOP (46). Anticholinesterases, such as physostigmine or chemical nerve agents, can cause intense ciliary muscle spasm, myopia, and miosis (47). Topical cholinergic blocking drugs, to include atropine, homatropine, and Mydriacyl®, can paralyze accommodation for varying periods of time and therefore would principally affect near vision (44). Sulfonamide medications, such as sulfacetamide, and Diamox®, a carbonic anhydrase inhibitor, can increase the refractive power of the lens, and thus induce myopia (44,47). Over 35 publications have described an acute transient myopia associated with medications that most likely induce transitory lens hydration changes (47). These include hydrochlorothiazide (48), tetracycline (49,50), promethazine (51), quinine sulfate (52), and spironolactone (53).

Antimalarials (quinine, amodiaquine, chloroquine, hydroxychloroquine) can cause transient ocular side effects, such as VF changes, papilledema, decreased accommodation, corneal edema, mydriasis, diplopia, retinal edema, and retinal hemorrhages secondary to drug-induced anemia. However, ocular side effects at the suggested dosage levels are rare (54).

Long-term chloroquine usage has been associated with impaired ability to accommodate. This can cause difficulty in quickly changing focus between near and distant objects which is typically described simply as "blurred vision." A reversible reduction in amplitude of accommodation has even been seen shortly after initiation of chloroquine (55). Hydroxychloroquine and chloroquine have been noted to cause an increase in the time it takes to recover macular function after bright illumination of the retina with a standard light source (macular stress test) (55). A 3-fold increase in macular function recovery time of patients taking 20 mg of hydroxychloroquine for one year was noted (56), while chloroquine therapy was noted to cause a 2-fold increase (57).

Vitamin A can induce papilledema secondary to induced pseudotumor cerebri and retinal hemorrhages secondary to drug-induced anemia. These side effects are usually only seen in infants and children, and most are rapidly reversible after discontinuing vitamin therapy (54).

Rarely, vaccines have been reported to cause transitory decreases in vision attributed to retinal hemorrhages secondary to drug-induced anemia (54).

HYPERVISCOUS STATES

Hyperviscosity refers to a reduction in blood fluidity which may or may not be measurable as increased whole blood or plasma viscosity. These abnormalities are usually due to a quantitative increase in one or more of the blood components. However, other causes include abnormal interaction between cellular and plasma components, increased cellular rigidity, and particular physicochemical characteristics of an abnormal plasma protein (e.g., cryoglobulin) (58). The hyperviscosity syndrome includes the following clinical features: visual or auditory disturbances; bleeding diatheses; headache; neurologic dysfunction; and hypervolemia (58,59). Examination of the retinal fundus during an episode may reveal marked venous engorgement, hemorrhages, and, in severe cases, disc edema. A predisposed patient, such as one with sickle cell anemia, may aggravate the hyperviscosity by becoming dehydrated, hypoxic, hypoglycemic, hypothermic or hypotensive, or by incurring an infection (58).

ENVIRONMENTAL IRRITANTS/TOXINS

A wide variety of environmental irritants and toxins such as snake venom can cause TVL (60). Environmental irritants such as smog, smoke, or fumes cause severe irritation to the eyes, to include superficial keratitis, resulting in blurred vision, discomfort, heavy lacrimation and conjunctival hyperemia, but usually induce no permanent injury (61,62). Exposure to such compounds has caused subjective visual symptoms at concentrations well below those causing respiratory discomfort (63,64). Thus, smoke or fumes in the cockpit may cause a relatively serious but usually transient visual incapacitation.

OPTICAL APPLIANCES/PHENOMENA

Several optical causes may initiate a TVL/TVO with no less of an impact than other pathological events. An aviator wearing contact lenses could have an abrupt transient visual disturbance due to dislocation of the lens; a foreign body beneath the lens; corneal pathology from overwear, tight lens, edema, abrasion, or infection; dirty lens; or more insidious phenomenon such as compromised stereopsis from inadequate optical correction resulting from contact lens dehydration or inadvertent switching of lenses in an anisometrope. An aviator wearing spectacles could suffer transient visual dysfunction due to fogging of lenses due to temperature or humidity changes, frame or lens displacement or loss, or alteration of an astigmatic or spherical correction due to altered pantoscopic tilt or wear of frames to enhance compatibility with other flying equipment (i.e., helmet, oxygen mask, headset, etc.). Lastly, a combination of factors, such as a keratoconic aviator with only sporadic HCL wear, may experience less than optimal correction of the refractive error.

CONCLUSION

In this review, we have compiled the various etiologies that can cause TVL/TVO. Particular emphasis was placed on those etiologies, which are either unique to the aviator environment or would be expected to occur more commonly in aircrew.

Table 1. Differential Diagnosis of TVL [3, 65, 66, 67, 68, 69, 70]

I. CARDIOVASCULAR
- Embolic
  - Arising from a carotid artery, arch of aorta, cardiac valves or intracardiac (secondary to dyskinetic wall segments)
  - Paradoxical (passes through a cardiac septal defect)
  - Carcinomatous
  - Disseminated atheroembolism
  - Decompression sickness (bends)
- Stenotic Vascular Disease
  - Carotid or vertebral artery atherosclerotic disease
  - Ophthalmic artery disease (fibromuscular dysplasia)
  - Carotid artery dissection
  - Carotid occlusive disease after irradiation
- Cardiac
  - Mitral valve prolapse
  - Atrial myxoma
  - Marantic endocarditis
  - Arrhythmia
  - Dyskinetic wall segment
- Vasculitic
  - Temporal arteritis
  - Systemic lupus erythematosus

II. PHYSIOLOGIC
- Hypoxic
- G stress
- Flash blindness
- Valsalva
- Vasovagal/syncopal

III. HEMATOLOGIC
- Hypercoagulable states
  - Waldenstrom's macroglobulinemia
  - Antithrombin III deficiency
  - Protein C deficiency
  - Protein S deficiency
  - Cancer
  - Pregnancy
  - Oral contraceptives
  - Thrombocytopenia
  - Antiphospholipid antibody syndrome
  - Hyperlipidemias
- Hyperviscous States
  - Waldenstrom's macroglobulinemia
  - Polycythemia vera
  - Sickle cell anemia
  - Multiple myeloma
  - Diabetes
- Anemia

IV. LOCAL ORBITAL OR OCULAR DISEASE
- Glaucoma (angle closure; pigmentary dispersion)
- Disc edema/papilledema
- Optic nerve drusen and other disc anomalies
- Optic nerve sheath meningiomas
- Orbital tumor adjacent to optic nerve
- Optic neuropathy associated with Graves' disease
- Post-traumatic optic neuropathy
- Photostress with maculopathy
- Pseudophakia
- Paraneoplastic photoreceptor retinopathy
- Keratoconus
- Barosinus pneumocele
- Optic neuritis
- Central serous retinopathy
- Vitreous heme/floater
- Ischemic ocular syndrome
- Impending BRVO/CRVO
- Impending BRAO/CRAO
- Hyphema
- Intraorbital masses

V. MISCELLANEOUS
- Migraine: retinal, cortical
- Hysteria/malingering
- Drugs (quinine, quinidine)
- After cerebral angiography
- Narcolepsy
- Environmental irritants
- Vector borne (wasp sting/snake bite)
- Trauma
- Metabolic (diabetes/nutritional)
- Optical causes
- Ornithine transcarbamoylase deficiency
- Spontaneous anterior chamber microhyphema
- Seizures
- Idiopathic
- Intracranial mass/occipital lobe tumor

Table 2. Aeromedically Significant Etiologies of TVL/TVO

I. Cardiovascular
- Arrhythmia
- Carotid (CRVO/BRVO)
- Myxoma
- Acute ischemic optic neuropathy
- Mitral valve prolapse

II. Physiologic
- Hypoxia
- G stress
- Valsalva
- Flash blindness (bleaching of rods/cones)
- Vasovagal/syncopal
- Decompression Sickness (Bends)

III. Ocular
- Migraine
- Optic neuritis
- Trauma (post-traumatic optic neuropathy)
- Optic disc drusen
- Barosinus pneumocele
- Glaucoma (pigmentary dispersion syndrome/acute angle closure)
- Papilledema
- Central serous retinopathy
- Keratoconus

IV. Other
- Drugs/medications
- Hematological (hyperviscosity)
- Environmental irritants/toxins
- Metabolic (hunger, nutritional deficiency)
- Optical Appliances/Phenomenon

Table 3. Sources of Emboli [6, 71]

	Type	Patient Age
CARDIAC		
Valves		
Rheumatic disease	Platelet/calcium*	Any age
Lupus	Platelet	Young women
Acute or subacute endocarditis	Marasmic	Damaged heart
Floppy mitral valve	Platelet	Any age; mostly women
Chamber		
Myxoma	Myxoma	
Mural thrombus	Platelet/clot	Older adult
CAROTID ARTERY		
Ulcerated plaque	Platelet/cholesterol ester	Older adult
Stenosis	Platelet	
Fibromuscular dysplasia	Platelet	Young women
OTHER		
Amniotic fluid	Debris?*	Young women
Long bone fracture	Fat*	Any age
Chronic intravenous drug users	Talc*	Any age
Disseminated intravascular coagulapathy	??	??
Lupus anticoagulant	??	??

*Produces retinal infarction; no amaurosis fugax.

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Spatial Visuo-Motor Compatibility in a Tracking Task

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1. SUMMARY

Two logically-related areas of study are discussed here: stimulus-response compatibility, which has to do with whether a signal and an operator's response to it are perceptually related – for example, whether both are located in similar parts of the operator's visual field – and manual tracking, in which an operator uses a control device to follow a moving signal. In our experiments, subjects moved a stylus that was constrained to move along a straight path, to track a target that also moved in a straight line. Either the stylus track or the trajectory of the target could be rotated so that they were either parallel, or so that they were at an angle to one other. Performance, measured either by time-on-target or by the RMS error between the subject's track and the desired track, was best when the target and tracking movements were parallel and in phase, or nearly so; and worst when they in, or close to, counterphase. Earlier work has shown that when both the signal and the location of the response are stationary, performance is best when their positions are compatible. The present results show that this holds for moving targets as well.

2. INTRODUCTION

This study is concerned with two similar phenomena that have been frequently studied separately, but seldom together: compatibility and manual tracking. The principle of compatibility emerged in the field of human factors shortly after World War II, when as part of a continuing effort to increase the rate of detection of sonar signals, a visual display was added to the conventional auditory display. Quite unexpectedly, this dual-modality display was not always advantageous: under certain conditions, which were termed incompatible, adding simultaneous visual information made detection of the target more difficult. This occurred, for example, if the auditory signal varied in amplitude, while the visual signal varied in spatial position. Compatibility required that both signals vary in, for example, intensity in a congruent way. This result, which Arnold Small presented at a meeting of the British Ergonomics Research Society in 1951, attracted the attention of Paul Fitts who described the compatibility principle as "a landmark of great significance with broad applicability" (Small, 1990).

During the following years, Fitts and his co-workers applied the compatibility principle not only to stimulus-stimulus (S-S) pairings such as those in Small's original study, but also to stimulus-response (S-R) and to response-response (R-R) combinations. Today, work in this area usually deals with S-R relationships, especially in ergonomic applications. Since Fitts' time there have been many studies of S-R compatibility in areas such as spatial coding; human information processing and motor performance; man-machine interactions; and the optimal design of displays or keyboards (see Proctor & Reeves, 1990; and Wickens, 1992, for reviews).

The second field of study, manual tracking and motor control, is even more venerable than compatibility: it goes back in various forms to the previous century, and has been the subject of countless studies (see e.g., Poulton, 1974; and Knight, 1987). In a typical manual-tracking task, a human operator moves a control in order to try to follow a moving target or to return a moving target to a desired position. Tracking has attracted considerable attention during the last half-century because it can be used to simulate many situations that occur in control systems, in which a human operator is required to manually adjust a control in order to maintain a given output: a classic example is that of a pilot who maintains aircraft attitude by moving his yoke so as to hold the artificial horizon at a certain position. By introducing response delay, phase lag, random noise, and other complications, the performance of highly-complex systems can be simulated for research and training.

Despite the apparent similarity between these two areas, there seem to be virtually no studies in which they are combined – for example, experiments in which the direction in which a target moves and the direction in which the operator responds are either the same or different. Among the few studies of this sort are one by Kenneth Craik and Margaret Vince, at the University of Cambridge (Vince, 1944), and another by Walter Grether at the U.S. Army Aero Medical Laboratory at Wright-Patterson Air Force Base (Grether, 1947). Both studies were carried out before the principle of compatibility was explicitly stated, and (other than transient performance decrements following a sudden reversal in the direction in which a control worked) neither showed compatibility effects that were large enough to be judged to be of practical importance, which may explain why research in this field was largely abandoned. A few later reports from the MRC Applied Psychology Unit dealt with the effects of 'unexpected' *vs* 'expected' results of control movement, but were not concerned with compatibility as such (Hammerton & Tickner, 1964, 1969).

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We have attempted to bridge this gap between compatibility and tracking research. Specifically, in two experiments we asked whether the relationship between the direction of target movement and direction of tracking can influence tracking accuracy. In the first experiment, the orientation of the target movement was kept constant while the orientation of tracking was varied; in the second, the direction of tracking remained constant while the orientation of the target movement was varied.

3. METHOD

The target was a small spot of light that moved with sinusoidal acceleration in a straight line, on a vertical screen. It started at the center of the screen and moved, beginning either to the left or right, through five complete cycles. The amplitude of motion was 16 degrees and the average velocity 3.3 degrees per second, so that each trial lasted approximately 48 seconds. The subject attempted to keep the signal inside a 0.6 degree wide window, the position of which moved as a stylus was moved in a track that lay horizontal on a table between the subject and the display screen. There was no lag in the system, and movement of the window was linearly related to movement of the stylus. Target motion and data collection were controlled by a PC (IBM 486) with a purpose-made timer card that allowed timing with an accuracy of 0.2 msec, independent of the computer time base.

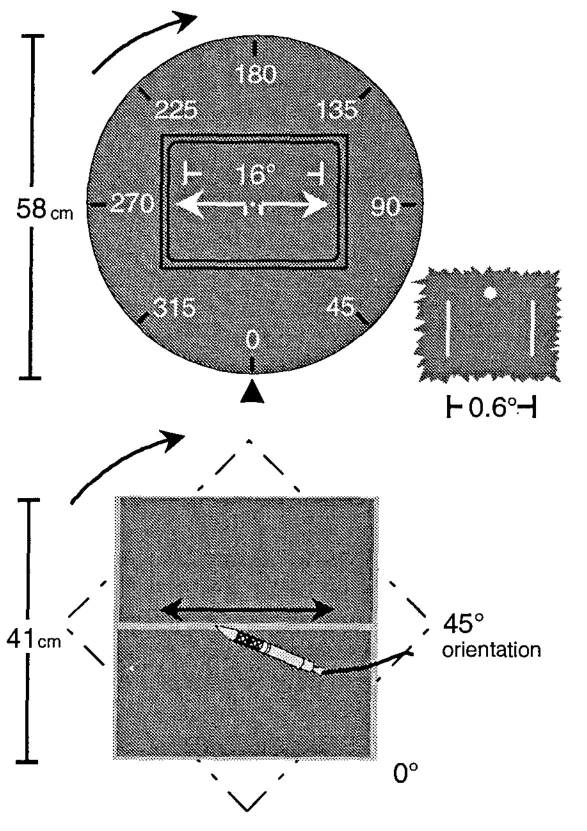

Fig. 1. Upper diagram: schematic view of the screen, as seen from the subject's position. The inset shows the target (light dot) and the tracking window. Lower diagram: tracking pad, as seen from above.

Both the screen and the response board could be rotated (Fig. 1). The angle between target trajectory and the direction of response was measured in degrees, with the reference, or zero-degree, setting defined as that in which the target moved along a horizontal line and the subject's response was in the fronto-parallel plane (i.e., perpendicular to the subject's line of sight, and thus parallel to the screen), in the same direction and with the same phase as the motion of the target. Head position and eye-screen distance (57 cm) were maintained by a chin and forehead rest.

Eight persons, four female and four male, aged between 18 and 34 years with normal or corrected-to-normal vision, served as subjects in Experiment I, and eight persons, again four females and four males, aged between 20 and 44 years in Experiment II. Four of the same subjects participated in both experiments. None of the subjects had previous experience in this or similar tracking tasks, but were given several practice runs before the main experiment.

In Experiment I the target motion was always horizontal, while the tracking path was rotated between trial runs through 360 deg in steps of 45 deg, so that the angle between target trajectory and tracking path varied from compatible, with target motion and tracking in the same direction, through incompatible, with tracking opposite to target motion. In Experiment II the subject always tracked across the fronto-parallel plane, while the orientation of the screen was varied in steps of 45 deg. The eight angular conditions were presented twice, with different initial directions of stimulus motion, in a balanced sequence across subjects in a Latin-square design. In order to test for the effect of practice, subjects were given three blocks of trials with rest periods. All trials were presented in a single session that lasted approximately 2½ hours.

4. RESULTS

Fig. 2 gives examples of the raw data. The dashed lines show the target position during a half-cycle of motion while the solid line shows how the subject moved the window during the same half-cycle. Subject AR, whose data is shown on the left, was clearly more accurate, as reflected in the discrepancy between target and the middle of the window (the ragged lower trace).

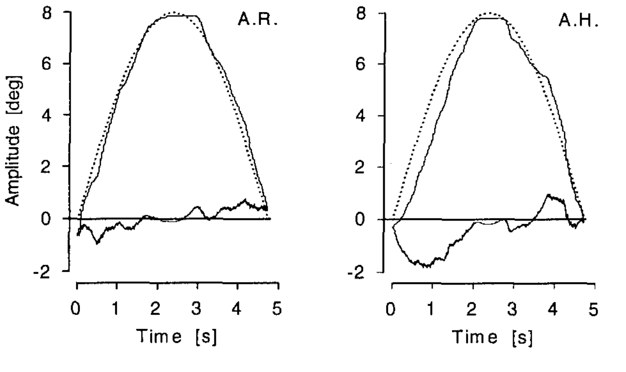

Fig. 2. Examples of raw tracking data for two subjects.

We used two methods to quantify performance: 1) the time that the target was kept within the window, expressed as per centage of the total duration of each trial, and 2) the root-mean-square (RMS) error between the position of the target and the position of the window.

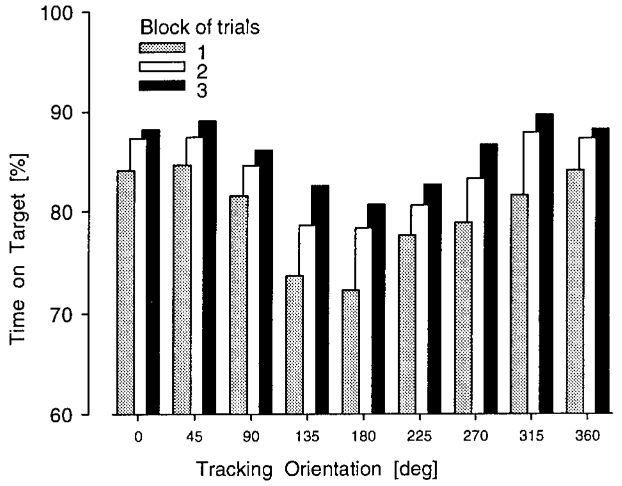

Fig. 3. Mean time-on-target for 8 subjects in Experiment 1, in which the orientation of the tracking pad was rotated.

Mean performance data, averaged across subjects in the first experiment (in which the orientation of the subjects' tracking response was varied) are shown in Fig. 3. Performance expressed by time-on-target changes quite systematically with tracking orientation. Performance is best when the target and tracking movements are compatible or nearly compatible (0, 45, 315, 360 deg) and there is a clear performance loss at incompatible orientations (135, 180, 225 deg). Similarly, the RMS error (Fig. 4) is smallest at the compatible orientations and largest when target motion and response direction are 180 deg out of phase.

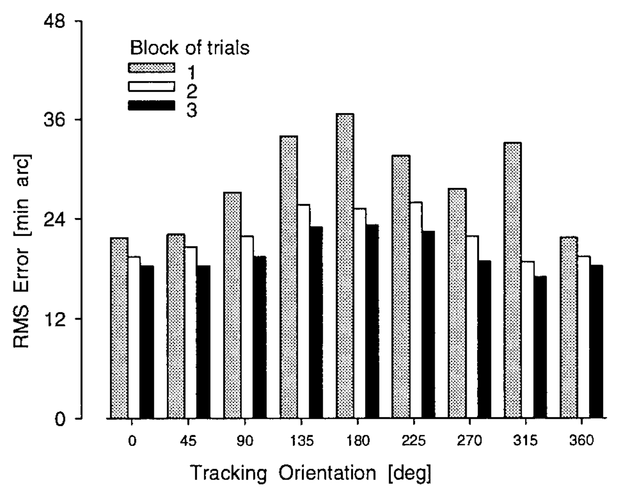

Fig. 4. Mean RMS error for 8 subjects in Experiment 1.

The three bars at each orientation are the three repetitions. As is almost universally the case in tracking tasks, performance improves with practice. The improvement in the second and third blocks of trials is similar at all orientations, so that the difference across orientations persists with practice.

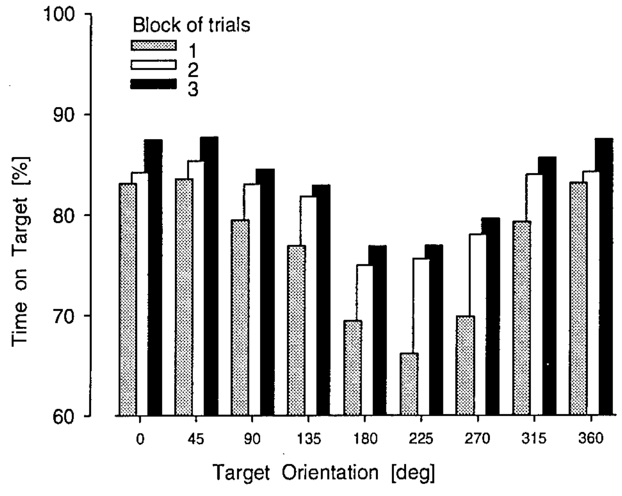

Fig. 5. Mean time-on-target for 8 subjects in Experiment 2, in which the orientation of the target trajectory was rotated.

Fig. 5 shows mean performance data obtained in Experiment II, in which the orientation of the target trajectory was varied. As in Fig. 3, time on target depends upon the relative orientation of the target and the response. However, the poorest performance is not at 180 deg, as it was in the first experiment, but at 225 deg: that is, it has shifted towards an oblique orientation at which the target trajectory is from upper-left to lower-right. Again, performance improves with practice, but the dependence on target orientation is preserved. Similarly, the RMS error (Fig. 6) shows a performance pessimum at 225 deg. At present we have no explanation for this curious anomaly.

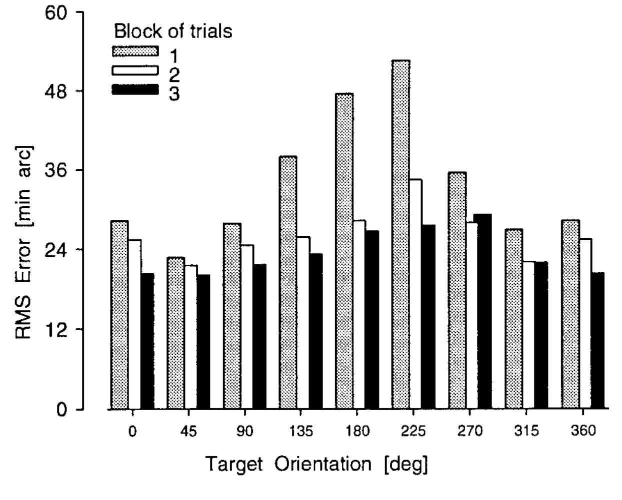

Fig. 6. Mean RMS error for 8 subjects in Experiment 2.

A three-way analysis of variance (Table 1) showed that the effect of orientation on both time-on-target and RMS error was highly significant. The order of trials, which reflects the amount of practice the subjects had, was also significant. The initial direction of target motion was never significant, and interactions between conditions were generally insignificant.

Factors	Performance Measure					
	Time on target			RMS error		
	F	d f	p	F	d f	p
	Experiment I (3-way ANOVA)					
Direction	2.2	1, 7	0.18	4.1	1, 7	0.08
Order of trials	26.2	2, 7	0.001	18.0	2, 7	0.004
Tracking orientation	10.4	2.9, 20.6*	0.0002	5.9	1.7, 12.1*	0.02
	Experiment II (3-way ANOVA)					
Direction	1.1	1, 7	0.33	0.02	1, 7	0.88
Order of trials	7.4	2, 7	0.03	8.8	2, 7	0.02
Target orientation	12.5	3.3, 22.8*	0.0001	5.77	1.8, 12.9*	0.02
D x O	6.6	1, 7	0.037	0.17	1, 7	0.69

* Greenhouse-Geisser adjusted d f

Table 1: Results of the Analysis of Variance.

5. DISCUSSION

These results offer clear evidence that manual control in visuomotor tracking depends on angular stimulus-response compatibility. Tracking performance is degraded as the angle between target motion and tracking motion increases; or in other words, tracking is best when target and tracking directions are compatible. This compatibility effect persists with practice, indicating that it is a genuine task-related effect, and not simply a result of subjects being more familiar with certain stimulus-response configurations. Similar results have also been found with static, rather than moving, visual stimuli (e.g., Simon & Wolf, 1963; Ehrenstein , Schroeder-Heister & Heister, 1989). Thus, compatibility between either display location and the location of the subject's response, or between the direction of the display movement and the direction of the subject's response can significantly affect performance, and should be taken into account in the design of control systems (Wickens, 1992).

Acknowledgement. We wish to thank Ludger Blanke for designing the timer card and Peter Dillman for his help in assembling the apparatus. Parts of this material were presented at the 1994 Annual Meeting of the European Chapter of the Human Factors and Ergonomics Society, in Dortmund, Germany, and will appear in Brookhuis, K.A., Weikert, C.M. and Cavonius, C.R. (eds.) *Human Factors in Training and Simulation.* Groningen: Traffic Research Center, 1995.

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LIMITATIONS OF C.N.S. FUNCTION IMPOSED BY VIBRATION IN FLIGHT

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INTRODUCTION

Vibration constitutes any form of motion that repeatedly alternates in direction.It is usually perceived by the senses as a series of sustained , mechanical, oscillatory disturbance.
In everyday life as well as in aviation, vibrational energy reaches the body directly, by means of contact with a vibrating surface, or indirectly, by transmission through intervening bodies such as solids or fluids.
When transmitted through air and bears characteristics in the audible range is treated as *noise*.

PHYSICAL CHARACTERISTICS

The simplest example of a vibrating system can be set by a system including a mass (m) connected to a spring (S) suspended by a rigid surface (Fig. 1) .
A displacement (x) of the mass will result in storing of potential energy in the spring coils which will transform into kinetic when the mass is released, and vice versa.This vibration can be described by

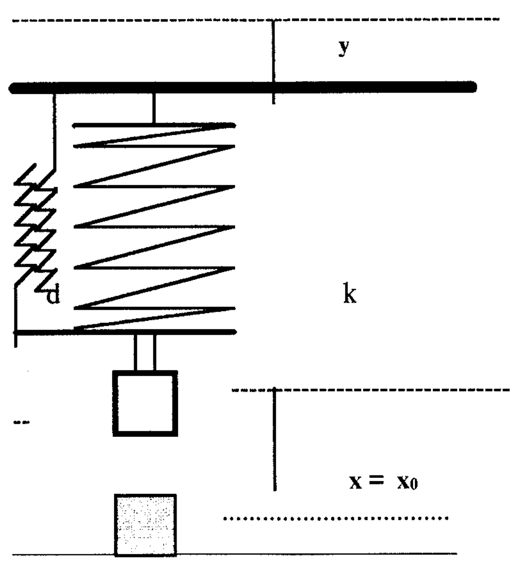

Figure I: A simple mass - spring system

two fundamental parameters: (a) the number of oscillations completed in the time unit (sec),called

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frequency (F) and measured in Hertz (Hz - 1Hz = 1 cycle per sec), and (b) the **amplitude** (x_0) of oscillation, representing the maximum displacement of the mass from the center point (O) of oscillation - for the example above, $x_0 = x$.
After the ideal mass-spring system is released, it will vibrate at a frequency, named the natural frequency (f_n), which can be predicted by the following form:

$$f_n = \frac{1}{2\pi}\sqrt{\frac{k}{m}}$$

where (k) represents the spring stifness and (m) its mass.

In an ideal system no energy is lost, and the oscillation of the mass could continue indefinitely.In real circumstances though, energy is lost by means of air resistance and friction in spring molecular level (thermodynamic heat), therefore the oscillation amplitude will decay and the vibration will cease in a certain time period.This system function is called **damping (d)** and vibrating systems can be build poccessing different damping qualities so random vibrational energy may be prevented from reaching the body by near-total consumption into damping systems structure.

At this point, if we condider the firm suspension surface of our example vibrating with a frequency (f) and amplitude (y), then the mass (m) is considered to undergo a forced vibration.
With increasing frequency, the amplitude ratio x/y may reach a maximum value (Fig 2), that is the surface vibration amplitude is cosiderably exceeded by the mass under the forced vibration.Then the surface and mass are in resonance and the frequency at which resonance occurs is called **Resonant Frequency (f_R).**

Although the ideal spring-mass system is convenient to study, real vibrating systems (including human body) are usually consisted of more then one vibrating masses, with individual damping properties, resonances and -correlated or not- elastic qualities obeying non-linear characteristics , that is elasticity varying with displacement.
In such complex systems it is convenient to consider each element behaving indepentently, with each responce acting additively to form the overall system responce.The technique applied to analyze a complex vibration signal into its constituent frequencies is termed "Fourier Analysis" and the plot of component amplitude against its frequency constitutes the **Vibration Spectrum.**

Vibration in Aviation Environment

The field of aviation vibration has been extensively

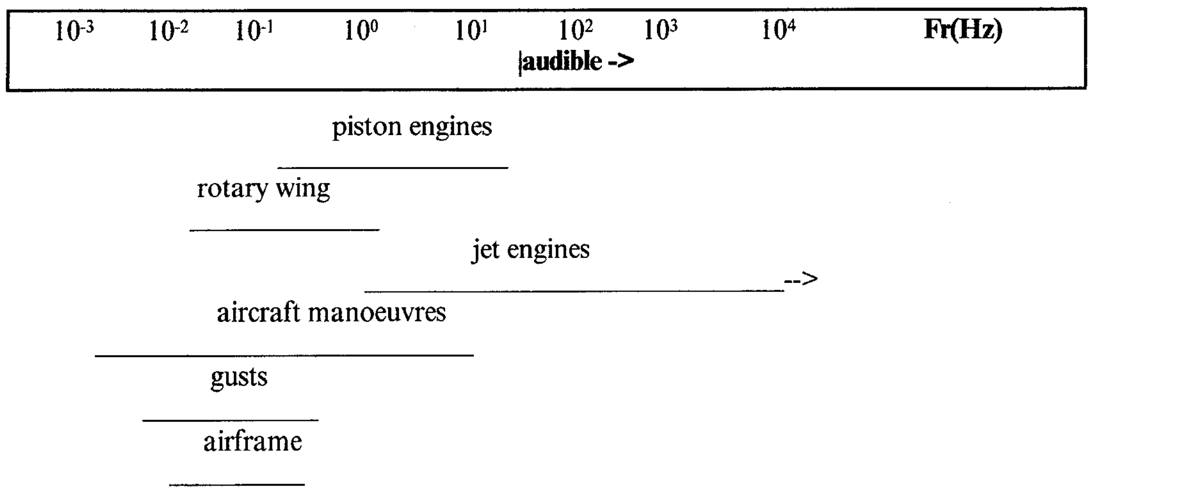

FIGURE 3: Sourses of aircraft vibration in frequency distribution (Adapted from Guinaurd,1972 [20])

explored by many workers as interest about new aircraft types and near-envelope flight conditions increased over time.
The principle sourses of aviation vibration[20,48] derive primarily from:

i) sourses within the aircraft, such as engine (turbine single or dual stage, propeller driven or piston engine), air conditioning, armament discharge and other mechanical or hydraulic systems, and

ii) environmental factors such as turbulence upon encounter or within flight configurations (low level high speed or over rough terrain), fuselage resonances and wing structure and loading

In Fig 3 vibration frequency elements are represented , according to aircraft type : rotary or fixed wing.The main

vibrational energy component for the fixed wing aircraft[47] lies in the low frequency domain (0.1-5 Hz), while for the rotary ones lies in the 5-80 Hz domain.
In everyday locomotion vibration frequencies lie in the 0.5-3 Hz region, therefore Central Nervous System (CNS) and modalities adaptation to this frequency bandwith meets with the accumulation of aviation vibrational energy and important resonanses in the 1-20 Hz area.
The outcome of the above coincidence may serve as cornerstone of CNS implications imposed by aviation vibration.

C.N.S. IMPLICATIONS

Vibration can physiologically influence CNS in two ways:

I. Physiologically, through

a. mechanical or biochemical effects on neuron cells or circuits, pertaining mostly to anatomical and structural resonanse effects

b. Altered sensory physiology, as observed in vision , inner ear function, propioception & kinaesthesis, either in receptor or sensor level, or in final integration of afferent information in sensorimotor cortex(perceptual process).Sensor function and perceptual process impact of vibration are often difficult to isolate and will be adressed consistently.

II.Psychologically, by means of

a.general stressor effects and

b.modified by vibration performance of psychomotor tasks, simple or complex ones, mainly concerning flight .

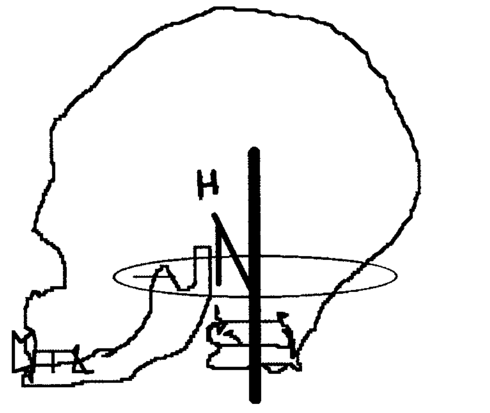

Figure 3: Head centre of gravity (H)

I. PHYSIOLOGICAL EFFECTS ON C.N.S.

a.Head Structural - Anatomical Effects

As mentioned above, the human body when vibrated behaves as a complex mass system yielding when seated two major resonances at the 4-5 Hz and 12-15 Hz area[48].
The head as main anatomical host of CNS stucture contributes in both resonant frequencies, but in a different mode :at 4-5 Hz there is a 1.5 fold vibration amplification, while at 12-15 Hz area a 2 fold increase[38].Nevertheless, the later resonance can be attenuated by the damping properties of the

trunk when standing but at the expense of the lower resonant area.

In addition, the presense of the head's center of gravity 3-4cm anterior to the axis of head

Fr(Hz)	Sensation	(0.1G).
0.1-0.5	nausea	
< 1	head motion	
1.0-2.0	soporific	
3.0-4.0	abdomen, chest, & shoulder oscillation	
5.0-8.0	uncomfortable	
9.0-10	soft tissue fluttering	
<30	vision unclear	
>30	tingling sensations	

Table I: Subjective Sensations of Vibration

rotation creates a second, in pitch angular head motion observed at 5-6 and 12 Hz .In this way, the head may oscillate with at least two degrees of freedom (vertical and in pitch, but the addition of head equipment such as a helmet supporting Night Vision Goggles (NVG) and Helmet Mounted Display-HMD (assemply which can reach experimentally 4 kg in weight[53], further complicates the head responce, producing a helmet pitch motion twice that of the head at 7 Hz.
Present consideration excludes the severe impact vibrations transmitted to the head directly or indirectly during aviation emergencies, such as a crush landing.

b.Systemic Physiological Effects

CNS function can be influenced by systematic effects of vibration, conserning mainly the respiratory and cardiovascular systems.No such important effects occur during vibration except an increase in metabolic rate and possibly true hyperventilation (Ernsting1961-[15]),with an underlying mechanism not yet fully understood.
Electroencephalographic activity modifications[1] during vibration have been under dispute due to motion artifacts interference .

c.Perceptual Effects

The vibration perception is served by most modalities: vestibular system (otolithic & semicircular canals activity), visual system (retinal activity and eye position),auditory system, propioception (touch-pressure receptors and body part position).It is only natural that vibration thresholds overlapse with motion perception thresholds, since vibration still remains a motion.

Vestibular research has yielded thresholds [11] for linear acceleration at 0.3 Hz from 0.014 to 0.018 m/sec2 with maximum sensitivity at the 0.1-2.0 Hz domain, and higher values for the Z body axis([8]Benson,1986).For angular, short-lived acceleration the threshold mean value is 0.3o/sec2 at frequencies <1 Hz ([25]Guedry, 1974).
At higher frequencies of oscillation threshold values rise : 0.02 m/sec2 at 50 Hz(Reiher 1946).
Subjective vibration sensations [20] are given in Table I.

Altered Modality function

A. vision

Effective man performance requires a stable view of the external world.The latter is achieved through stabilizing the foveal image by two main neural control mechanisms:

I. The Vestibulaionr-Ocular Reflex (VOR), an open loop system utilizing information from the vestibular receptors to compensate for head angular movements, by generating a slow ocular countermotion interrupted by a fast resetting of gaze (slow & fast component of this nystagmic motion)

Hz	Symptom
< 25	heard if intense
< 18	pulse series
5-10	pressure pulses, (>155dB) ear fulness & pain

TABLE II: Infrasonic Vibration

II. A visually facilitated feed back mechanism, consisted of two components:

(a) The Pursuit Reflex (PR), utilizing retinal velocity error for centering an object of interest in the fovea, and

(b) The Optokinetic Reflex (OR), utilizing relative retinal image position, thus allowing the eye to follow large moving visual fields with possibly no fixation target.

The Vestibular-Ocular Reflex (VOR) is a three neuron fast reflex and bears dynamic characteristics(Benson 1970[(4)],Hixson 1974[(25)]) which excibit optimal adaptation for natural head movements in the 0.5-3 Hz band : A gain (the amplitude ratio of slow phase eye velocity to head velocity) of unity and a phase relationship (temporal shift between stimulus and responce) of zero.In this way, VOR is seen to preserve visual acuity in oscillating subjects reading a stationary target up to 9-10 Hz[(6)]

However, the Pursuit Reflex (PR) enables man to track moving targets with eyes alone and posesses the following limitations: it collapses when target velocity exceeds 40-60^0/sec or oscillates above 1-2 Hz (13,53).They will appear in a subject trying to read a visual display which undergoes oscillation in varying frequencies (6).

When a subject undergoing angular oscillation ([(6)]Benson & Barnes 1978)is trying to fixate on an moving with the head display vestibular nystagmus generated by VOR is effectively suppressed at low frequencies (<0.5 Hz), but with increasing frequency there is a progressive supression breakdown which produses gain & frequency characteristics similar to PR.

The effectiveness of VOR may be measured in terms of the ratio of the supressed eye velocity over the one observed in the dark (identical conditions).The PR effectiveness is accessed by the pursuit velocity error, that is the difference between target and eye velocity, expressed as a ratio of target velocity.Measurements of pursuit and supression have produced no actual difference between pursuit velocity error and the suppression amplitude ratio [(2)] .Alcohol intoxication degraded effectiveness of both suppression and pursuit in a precise manner(Barnes 1983).

In general, clinical evidence (Dichgans 1979-[12]) support the similarity of VOR Suppression and PR, but still considered not identical : it is possible that they both share common neural circuitry.

When an aircraft enters turbulence, low frequency vibration affects both pilot and cockpit structures, with spectrum density heavily emphasizing the 1-10 Hz band,in which (specially >2 Hz) the VOR suppression is inadequate.

Therefore, the display of a HMD will be seen under visual acuity decrement unless space stabilized .Display stabilization can be implemented[(53,54)] by measurement of rotational acceleration at the display and feeding it back as position correction signal to the display.The net result will appear as a anti-phase deflection of the image in the yaw & pitch axis with respect to the display.In a flight trial of such a system[(53)] a profound improvement in mumericals reading time (25") and reading error (4%) was shown with respect to unequipped flight (40"- 18%), scores resembling ground values(21"-0.4%)

A further blurring of vision can be elicitated for higher frequencies of oscillation : at frequencies above 30 Hz an increasing angular eye movement is obsereved [(49)] reaching a mean gain of 3.0 at 70 Hz , possibly attributed to intra-ocular structure resonance, particularly the one of the lens.

inner ear

As seen previously, vibration frequency spectrum may overlapse with audible spectrum (18-

20000 Hz), thus perceived as sound, or usually as noise.

Infrasound vibration though, carrying much of the spectrum energy, is of particular importance precipitating symptoms [48] shown in Table II .After exposure to intense infrasound vibration a small Temporary Threshold Shift (TTS) (von Gierke[52] has been ropotred together with eardrum vascular injection.Similar results have been obtained using infrasound together with white noise, however the TTS was smaller[21].Nausea, balance disorders, vertical nystagmus have also been reported.

kinaesthesis & propioception

During body motion kinaesthetic afferents derive through the function of stretch receprors such as muscle spindles in a muscle's boby and Golgi tendon organs embedded in muscle tendon bodies.
These afferents integrated with touch & pressure afferents,vestibular, auditory and visual cues provide CNS with neccessary input to determine position and facilitate control of posture(Sherrington,1906-[42,43]).
On the other side, mechanical vibration of a limb muscle (Hagbarth & Eklund, [22]) through spindle receptors activation causes muscle reflex contraction known as **Tonic Vibration Reflex (TVR)** and possibly limb illusory motion.This illusion remains in the restrained limb [17,18] and may exceed limits of physical position ([10]) and are known as **vibratory Myesthetic Illusions.**

In experiments by LACKNER & LEVINE[29](1979) application of 120 Hz vibration on different body sites such as in Achilles tendon elicited an illusory falling /moving forward motion, in a sternocleidomastoid the illusion of rotation/tilt of head to opposite site, etc.
In darkness, such postural illusions can be elicited by appropriate manipulation of vibration site at any desired direction.Microneurographic records confirm that vibration rather selectively excits spindle Ia afferents, eliciting 1:1 driving up to 80-100 Hz([38]). Nystagmoid activity was recorded compensatory to the apparent motion and a concordant motion of a small target light, constituting the **propiogyral illusion.**

Whatever the experimental conditions, the oculomotor system always reacted to vibration stimuli of propioceptive afferents even in the absense of corresponding visual stimulus[49].
This illusion depicts an aspect of the spatial constancy mechanisms utilised by CNS to integrate postural afferent information with other modalities stimulation patterns.
Correct information on limb position may seem to be available to CNS at a subconsious level even if position perception is disturbed through vibration[45]

Another vibration induced CNS effect is considered to be the inhibition of spinal reflexes in man after long term whole body vibration [37], outlasting the stimulus.(Long lasting afferent input from extero & pripioceptive activation may be treated by the CNS as a nociceptive input and opposed by a gating like mechanism activation.)
Further research revealed that central inhibition is a function of vibration amplitude, rather than frequency[30] and exemplified in the 10-30 Hz band.

II.PSYCHOLOGICAL & PERFORMANCE EFFECTS

a.General Effects

Still the pilot's main task is one of manual control (continuous visual & motor).A series of other (secondary) tasks are superimposed during flight, which may well include monitoring of displays, maintaining an arousal status adequate for proper and immediate responce to flight visual & auditory signals representing emergencies or procedural demands and communication attending.
Vibration can affect all of these elements of pilot's job adversely and simultaneously increase the physiological cost of meeting a given performance creterion.This adverse effect influences flight in two main ways:

i. Interferes with the skilled use of use of hand and eye, specially in the 1-10 Hz region by enforcing vibration phase & amplitude differences between the pilot and his instrument panel.It is also possible for the vibration to alter the normal pattern of neuromuscular activity, depending upon its intensity and frequency .

ii. Vibration combines with task performance stress and with other stressors, such as noise, physical discomfort,alarm,fatigue contributing to the overall performance impairment by acting distractively or eroding pilot's motivation. There is also evidence that vibration disrupts central cognitive mechanisms utilized during information processing in Short Term Memory[44]

Accel(G)	Rating
<0.05	negligible
0.01	slight
0.1-0.15	moderate
<0.3	heavy
>0.3	severe

TABLE III: Turbulence rating

b.Subjective rating of vibration

Low frequency (0.5-2 Hz) turbulence penetration with high speed aircraft [40,56,34] evidence exhibit a subjective rating of vibration for the Z-axis (vertical), shown in Table III.
Rating for pitch or roll induced oscilation [28] exhibits less tolerability: amplitude of 0.1-0.15 G is now rated "annoying".

c.Central Effects upon Performance

Vibration Stress in flight is accossiated with fatigue and decrement in secondary task performance such as interpetation of information from displays reported during heavy turbulence flying.Incresed physiological effort is recruited to maintain performance on a primary task while a secondary one is attended to[7].Vibration is seen to superimpose an additional load to the physiological effort demanded to complete the task. Under heavy demand, the subject will gradually abandon the secondary task.This conforms with the fact that pilots in high-speed low-level flight experience great difficulty in attending to anything else but terrain following [35,41], an effect exemplified with time[23,27].

d.Vibration effects on Psychomotor Performance.

Simple performance

Simple reaction time tests have shown no significant performance decrement.Still,paradoxic facilitation may occur due to a vibration arousal influence[21,26,14].
Performance of tasks requiring fine positional control can be affected only because of body resonances as stated previously and are not attributed to CNS effects.

Complex Performance

Although different flight tasks incorporate various often not comparable aspects , vibration along body's Z-axis is seen to impede and disrupt continuous tracking task performance, provided it bears certain frequency characteristics: spectral peak in the 2-16 Hz , specially around 4 Hz.
Error scores increase over 0.01 G mean(RMS) seat acceleration amplitude and above 0.25 G performance is seriously obstructed, deteriorating with time due to supervening fatigue effects.
Intense noise(110 dB SPL) enhances degradation of tracking skills by vibration (Frequ. 5 Hz), suggesting a central factor[24].

Performance in X or Y axis is similarly influenced, though different body response characteristics located the vulnerable frequency in the 1.5-2 Hz domain.
Procedural errors may also appear during heavy vibration[57]. In a terget recentering task, vibration appears to pose a velocity error[36] in hand performance, specially when an helicopter stick instead of an arm side controller is used.

Speech effects

Speech produced under vibration can be substantially disturbed by modulaton of air flow velocity through the respiratory airways caused by the thorax-abdomen resonanses, and by the vibratory deformation of speech organ, mainly the mandible.
The above result in a tremolo-like quality of speech attributed to phonems amplitutude modulation, exerting an intellegibility effect appearing mostly at 6-8 Hz [33] and X-axis vibration (0.5 G) for the semi-supine subject.Speech tremolo is often accompanied by a fundamental frequency instability (jiter), bearing a combined impression of a fragmented vowel. Decreased intellegibility due to masking noise was seen for X- & Y-axis vibration and also for increasing acceleration levels.
Speech spectral tilt is known as the amplitude relationship between the high and the low frequency components of the speech spectrum.
Vibration raises speech fundamental frequency[31.32,33] and energy in the higher spectrum frequencies (Vilkmann [51]) with a subsequent decrease in spectral tilt.This effect, though is not vibration specific (MOORE,1990[9]), but merely a stressor effect posed on speech: increased vocal effort leads to increased laryngeal musculature tension reflected in fundamental frequency increase and elevated high frequency contribution to speech spectrum, thus a decrease in spectral tilt.

DISCUSSION

Vibration influences body as a whole, threrefore individual reference to CNS effects alone is rarely seen in literature.These effects may be manifestated by two different approaches , as above : the first reflects the physiology effects and the second the performance aspects.

Physiological effects tend to fall into effects attributable to:

1. the differential vibratory movement of CNS structure against the disclosing skull cavity , which is exemplified when vibration frequency reaches resonant areas (frequency depentent) and

2. the general stress effects imposed upon sensors and body systems physiology, both vibration frequency and intensity dependent.

Psychological and performance effects include indirect efforts to access higher cerebral functions by means of changes in performance and speech and to determine the overall contribution of vibration in flight stress.However,relatively little research has been directed towards vibration cognitive function impairment , as opposed to research on modalities perceptual integration.

Anatomically, vibration effects on CNS may be demonstrated in crush biodynamics, where high intensity stimulus precipitate CNS lesions known as Coup and Contre-Coup lesions and stimuli of lesser intensity give rise to concussion pathophysiologic events.
However, aviation environment acceleration overlapses in frequency with everyday locomotive vibration , but still the great intensity scales and vibration spectrum met in aviation together with certain observations leave ample grounds for concern.
The great point of interest lies in the region of CNS occupying trema magna, that is brain stem.Shock waves are mechanically generated in this area, mainly because it represent the point of entrance of soft tissue in the rigid skull.Rotational forces with seperatory potentials may also impact this area long before impact detection in endocalvaric structure.In addition,we are only reminded that helmets adress merely linear acceleration impact issues. Neurofibrosic lesions and amyloid deposits are seen in the area in boxers.In concussion pathophysiology, biochemical evidence of neuron fiber seperation and bloob-brain barrier disturbances, among others , have been detected.

If we consider CNS behaviour towards acceleration a continuum, the question of detection of vibration functional(or not) lesions in the area still remains open and presents a central point in consiousness and reticular formation physiology, as the later is mainly considered to act as the anatomic platform of consoiusness, common to all aspects of consiousness research : G-Loc, trauma, sleep & respiration physiology, neurology & neurosurgery among others.

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3D Analysis of Vestibular Function and Dysfunction

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SUMMARY

Using a new 3D motor-driven rotating chair and a 3D magnetic search-coil system, we investigated the 3D properties of the vestibuloocular reflex (VOR) in normal human subjects and patients with acute unilateral vestibular lesions. Subjects were rotated sinusoidally in the horizontal (about the earth-vertical axis), as well as in the two vertical semicircular canal (SCC) planes (about an earth-horizontal axis). In normals the responses were symmetrical with an average gain of the torsional VOR of about 0.4 and of the vertical and horizontal VOR of about 0.7. In patients there was a reduction and asymmetry of the VOR gain that was suggestive for a unilateral lesion of either the horizontal or anterior canal alone or a combined lesion of the anterior plus horizontal canal on one side. This new method allows not only to test the function of single SCC pairs but it gives also insight into the complex 3D organization of the VOR.

INTRODUCTION

The VOR helps to stabilize the retinal image by rotating the eyes to compensate for movements of the head. In the past, due to limitations in the methods, the VOR has usually been studied one-dimensionally both in normals and in patients with vestibular lesions, by examining its horizontal, vertical or, more recently, also torsional component in isolation. The input and output of the VOR (head velocity and eye velocity) were regarded as scalar quantities (i.e., real numbers), and the reflex was characterized in terms of its gain, which is the ratio of VOR output to input: eye velocity over head velocity. Ideally, the gain is -1, meaning that the eye rotates at the same speed as the head but in the opposite direction, so as to remain stationary in space. In reality, however, the input and output of the VOR are not scalars but three-component vectors (the angular velocity vectors of the head and eye) having not only magnitudes but also an infinity of possible directions, and so a more complete characterization of the VOR requires a description, not only of the relative sizes of the eye and head velocities, but also of their relative directions, i.e., the axes about which the eye and head spin.

To study the VOR in all three rotational degrees of freedom one must be able to stimulate the subject in 3D (input) and to record the resulting eye movements (output) in 3D. With the development of a 3D vestibular stimulator and the use of the 3D magnetic search-coil technique we were able to evaluate, for the first time, the 3D properties of the VOR in normal subjects and in patients with acute unilateral vestibular lesions.

METHODS

Sixteen patients with acute unilateral vestibular lesions (vestibular neuritis) and ten normal subjects without oculomotor or vestibular abnormalities were tested with eyes open in complete darkness.

We used a right-handed, 3D Cartesian coordinate system determined by the field coils with the horizontal plane being earth horizontal. The standard coordinate system is constructed by drawing an x-axis pointing forward in the horizontal plane (torsional direction), a y-axis pointing left along the interaural line (vertical direction), and a z-axis pointing up (horizontal direction), orthogonal to the horizontal plane. Angular eye position and velocity vectors are expressed in this coordinate system with positive values indicating leftward, downward and clockwise rotation of the eye (as seen from the subject's viewpoint). The magnetic field-search coil technique was used to measure angular positions of the head and left eye, relative to the bulb housing the subject, in all three dimensions.

Spontaneous nystagmus was recorded in darkness for one minute and then subjects were rotated sinusoidally in a computer-controlled rotating chair at .3 Hz with an amplitude of $\pm$ 20° and a maximum speed of 37.5°/s about fixed axes. The rotation axes were body-vertical (for horizontal

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rotation in yaw, stimulating mainly the horizontal SCC: HOR) with the rotation axis earth-vertical, and in the idealized planes of the vertical SCC. The latter stimulation axes were approximately orthogonal to the planes of the two vertical SCC pairs, with the stimulation axis earth-horizontal and the head turned either 45° to the right (pitch-roll stimulation in LARP stimulating mainly the left anterior and right posterior SCC) or 45° to the left (RALP: right anterior - left posterior SCC).

RESULTS

Fig. 1 shows individual responses of a normal subject in A and a patient with an acute leftsided lesion (3 days after the onset of symptoms) in B. Eye (continuous lines) and head (dotted lines) velocity data are plotted against time, with various inputs. Each row in the figure corresponds to one component of eye velocity, with torsional velocity E(T) plotted in the first row of each graph, vertical E(V) in the second, and horizontal E(H) in the third. Velocities in the first column show the eye movements seen when the head is stationary. Under this condition, the eye velocity is 0, i.e. there is no spontaneous nystagmus. The second column depicts the eye velocity response to stimulation in the LARP plane (pitch-roll stimulation), the third depicts the response to RALP stimulation, and the fourth to stimulation in HOR. For comparison, the components of head velocity are superimposed on the eye velocity traces. Head velocity has been multiplied by -1 to visualize more easily how well eye motion compensates for head motion.

Several general properties of the normal 3D VOR are shown on in A. First, the horizontal eye velocity response to horizontal stimulation (lower right corner) and the vertical response to stimulation in LARP and RALP (middle row) are larger than the torsional components (upper row). Second, there are no obvious asymmetries and no appreciable phase lags or leads. Third, there is some crosstalk in the VOR.

In the patient (B) with the head still (left column), there is a considerable spontaneous nystagmus, with horizontal (slow phase to the left), vertical (down) and torsional (counterclockwise) components. As expected with a left-sided lesion, the horizontal VOR response was weaker for rotation toward the left and, in the vertical canal planes, for rotation toward the excitatory direction of the left anterior canal.
Although these time plots are informative, we can often get a clearer impression of VOR geometry by dropping the time dimension and plotting eye velocities as vectors in 3D space. To show all three dimensions, we draw these vectors in three views, once as seen from the front of the subject, once from the subject's right side and once from above, with the view indicated by the schematic heads (Fig. 2 and 3). For all stimulation directions we calculated the maximum slow phase eye velocity. For each subject, maximum velocities were averaged over 20 s of consecutive sinusoidal stimulation to yield a maximum slow phase eye velocity vector for that subject.

Fig. 2 shows the data of the normal subjects. The filled squares and error bars show the means and standard deviations, averaged over all normal subjects, of these vectors for each direction for each stimulation axis. All velocity vectors are plotted according to the right hand rule. In the front view (left column), the vertical component of eye velocity is plotted on the abscissa and the horizontal component is plotted on the ordinate. The right side view (middle column) shows the torsional and the horizontal component. The top view (right column) shows the torsional and the vertical component. Thick dashed lines indicate the stimulation vectors, which are purely vertical for HOR (lying on the ordinate in the left and middle row, the length of the axis indicating maximum head velocity). For RALP and LARP the stimulation vectors can best be seen in the top view in the right column (lying halfway between the torsional and vertical axes = roll-pitch stimulus). In the left and middle columns the vertical and the torsional components of head velocity are shown on the abscissa, the length again indicating the maximum torsional and vertical velocity component (71% of maximum chair velocity = the projection of the roll-pitch stimulus onto the vertical and torsional axes).

The fact that the horizontal and vertical responses are stronger than the torsional is now visible from the fact that the eye velocity vectors for RALP and LARP stimulation tilt away from the stimulation axes (above view on the right column) toward the axis for vertical rotation (the ordinate). This means that the eye velocity vectors elicited by a roll-pitch stimulus in LARP or RALP are not aligned with the simulation axis. Furthermore, even though these are pure roll-pitch stimuli, there are considerable horizontal crosstalk components of the eye velocity vector. For stimulation in HOR a pure horizontal stimulation produces an almost pure horizontal eye velocity (data points lie close to the horizontal stimulation axis (ordinate in the left and middle figure).

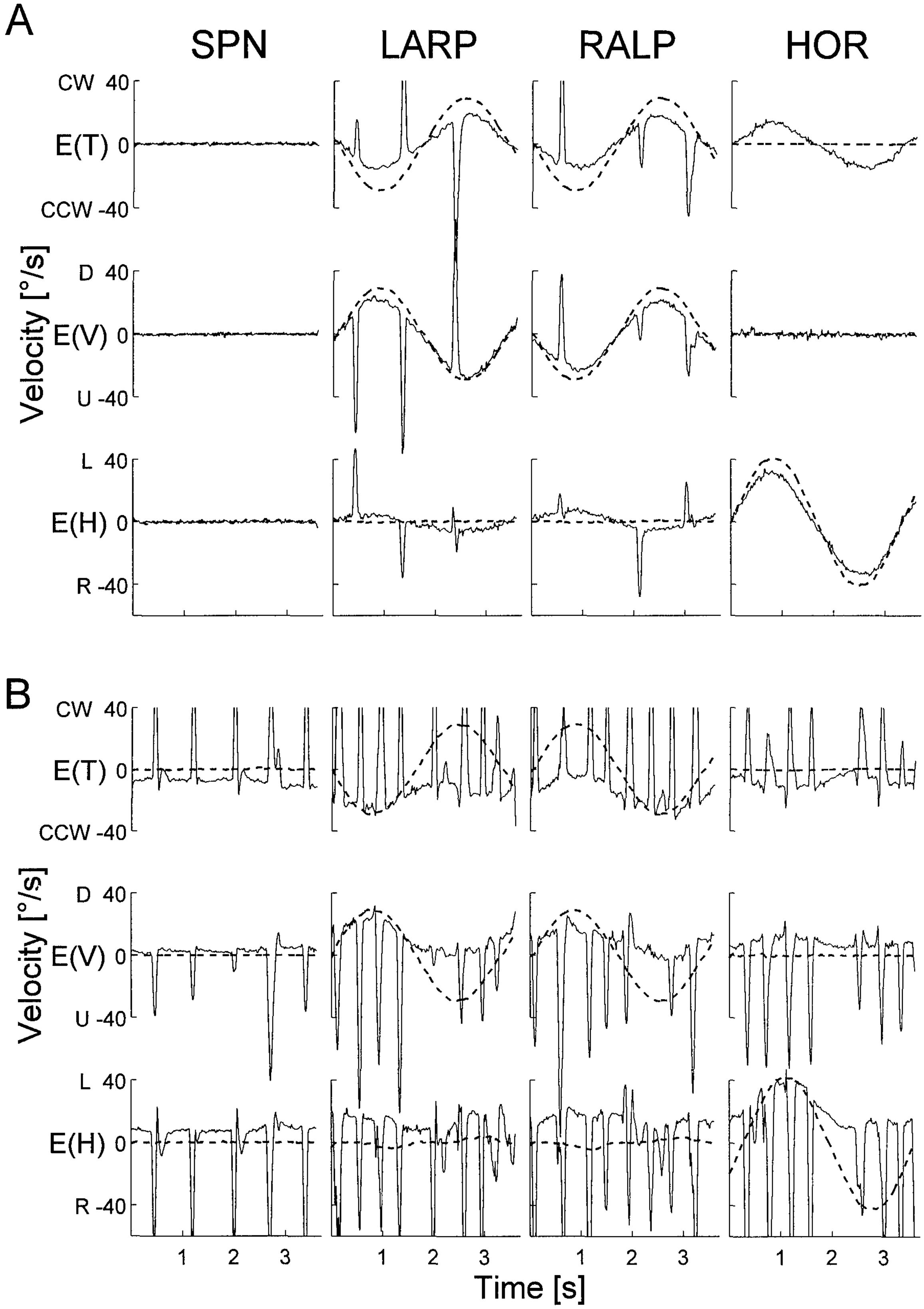

Fig.1: Original data of a normal subject (A) and a patient with a leftsided lesion (B). Eye (solid) and head (dashed) velocity data are plotted against time, with various inputs. The head velocity has been multiplied by -1. In the normal subject responses are symmetrical. The torsional response is about half as strong as the vertical and horizontal. In the patient, with the head still, a considerable spontaneous nystagmus is shown in the left column with slow phase to the left, down and counterclockwise. In accordance with a leftsided lesion, the horizontal VOR response was weaker for rotation toward the left and in the vertical canal planes for rotation toward the excitatory direction of the left anterior canal. (E(T): torsional; E(V): vertical; E(H): horizontal eye velocity; SPN: no head movements (spontaneous nystagmus); LARP; RALP, HOR: sinusoidal stimulation in the left anterior-right posterior SCC plane, in the right anterior-left posterior plane, and in the horizontal plane).

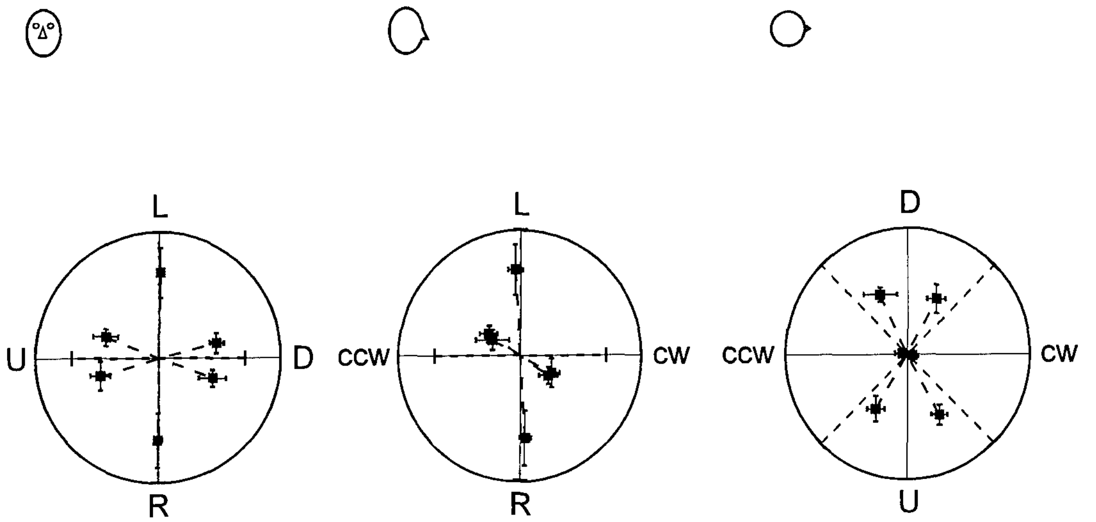

Fig. 2: Three-dimensional representation of the average maximum eye velocity for each direction for each stimulation axis of all normal subjects. The vectors are drawn in three views, once as seen from the front of the subject (left column), once from the subject's right side (middle column) and once from the top of the subject (right column), with the view indicated by the schematic heads. All velocity vectors are plotted according to the right hand rule. With thick dashed lines the stimulation vectors are denoted.

To quantify the acute effects of a unilateral vestibular lesion we first calculated the average speed of the slow phases of spontaneous nystagmus in the dark during a period of 20 s. To test for dynamic asymmetries we calculated the average maximum eye velocity for each direction and each stimulation axis and plotted the resulting vectors into a schema identical to Fig. 2. Fig. 3 shows the magnitude and direction of the average maximum eye velocity (filled circles connected with continuous lines) for both directions for each stimulation axis of the patient shown in Fig. 1 B. For comparison the averaged data of the normal subjects are also shown (filled squares connected with dashed lines).

This figure illustrates several effects of a unilateral vestibular lesion on the 3D properties of the VOR. The fact that the patient has a spontaneous nystagmus leads to a shift of the data crosses away from the origin of the coordinate system. The spontaneous nystagmus is represented as the data point (eye velocity for zero head velocity) to which all other data points are connected by solid lines. Around this value stimulation in the canal planes induced a modulation of spontaneous nystagmus that was asymmetric for stimulation in HOR (smaller eye velocity when rotated in the excitatory direction of the left horizontal SCC (lh)) and in LARP (smaller eye velocity when rotated in the excitatory direction of the left anterior SCC (la)). No significant asymmetry was found in this patient for stimulation in RALP. However, responses are not only asymmetrical but also remarkably distorted, even during excitation of functioning SCCs. The large crosstalks indicate a profound disturbance of the normal geometric organization of the VOR. Stimulation in HOR produced not only a horizontal component but in addition also a vertical downward component (relative to the spontaneous nystagmus). Stimulation in the nonaffected plane (RALP) led to inappropriate components with a relatively to high horizontal crosstalk component when the anterior SCC on the healthy side was excited. It is likely that these crosstalks are due to the missing or reduced dynamic inputs from the lesioned SCC afferents.

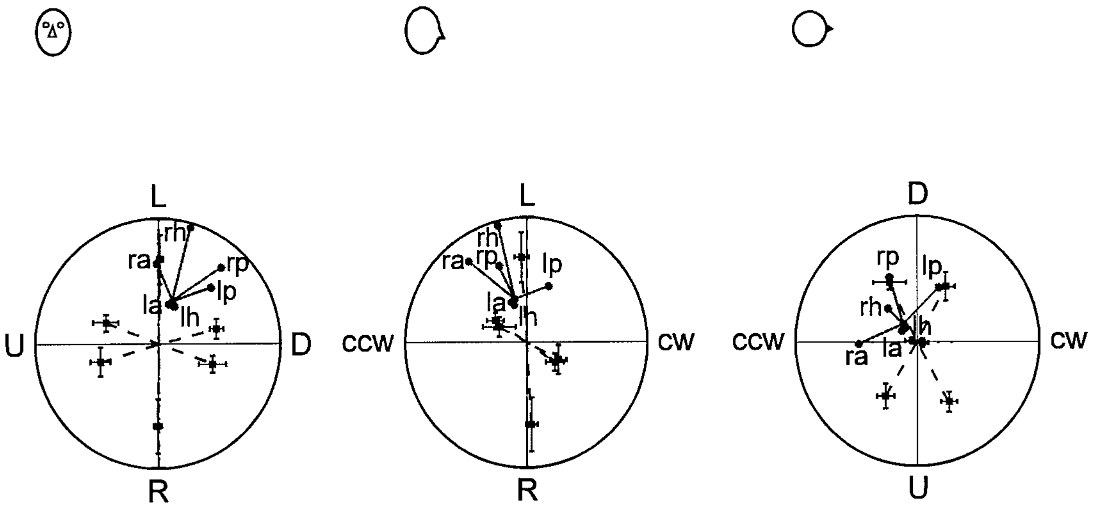

Fig. 3: Magnitude and direction of the average maximum eye velocity (solid) for both directions for each stimulation axis of a subject with a leftsided lesion (normal data: dashed lines). The patient had a spontaneous nystagmus leading to a shift of the data crosses away from the origin of the coordinate system. The spontaneous nystagmus is represented as the data point (eye velocity for zero head velocity) where all other data points are connected to with solid lines. Around this value stimulation in the canal planes induced a modulation of spontaneous nystagmus that was asymmetric for stimulation in HOR and in the vertical SCC plane when rotated in the excitatory direction of the ispilesional anterior SCC. No significant asymmetries were found in the other vertical SCC plane. There are also remarkable distortions of the responses when rotated toward functioning SCCs with large crosstalks indicating a profound disturbance of the normal geometric organization of the VOR.

To quantify the asymmetries for stimulation in the different planes we calculated the magnitude of the average maximum eye velocity corrected for spontaneous nystagmus in each patient and determined the directional preponderance. From the normal data we calculated a normal upper limit of 15% asymmetry (mean plus two standard deviations of the normal data). In most cases with significant dynamic asymmetries the analysis suggested a combined unilateral lesion of the afferents of the horizontal and anterior SCC. In a few cases the analysis suggested a lesion of just the anterior or horizontal SCC on one side, while the afferents of the posterior SCC again seemed to be spared in all cases.

DISCUSSION

This study presents data on the 3D properties of the human VOR in normals and in patients shortly after an acute unilateral vestibular lesion.

The oculomotor output of vestibular stimulation is anisotropic, i.e. the horizontal and vertical VOR differ from the torsional VOR with regard to gain (the torsional gain being only about half as strong as the horizontal and vertical). Even normal subjects show consistent crosstalk, especially when stimulated in the RALP and LARP planes, producing eye rotation axes that are not aligned with the head rotation axis (Fig. 2). There are several reasons for this behavior. One is the different VOR gains of the horizontal and vertical VOR on one hand and the torsional VOR on the other [1,2,3,4]. Crawford and Vilis [5] reported the same pattern of misalignment in monkeys and showed that a linear VOR with weak torsional gain (relative to vertical or horizontal) must yield eye velocity vectors that are systematically misaligned with head velocity when the latter has both torsional and vertical or horizontal components. Thus eye and head rotation axes are not aligned in general, but only for rotations about the body-vertical (yaw) and interaural (pitch) axes and for stimulation in the naso-occipital (roll) axis [4]. Actually, because vertical and horizontal gains tend to be about equal, eye and head axes may be well aligned for any head rotation about an axis in the frontal

plane. Since most head rotation axes used for eye-head gaze shifts lie within about 15° of this frontal plane [6], eye and head axes may be reasonably well aligned for most natural head movements.

A sudden unilateral lesion of the peripheral vestibular system abolishes the tonic neuronal discharge (resting activity) in the vestibular nerve on that side. The resulting imbalance between the tonic input of the two ears leads to reflexive eye movements (spontaneous nystagmus), since a difference between the firing rate of the two sides is the signal to the central vestibular system that the head is rotating. Consequently, the vestibuloocular reflex produces eye movements toward the side with the lower tonic firing rate, resulting in fast phases toward the good ear.

Both sides are connected via the vestibular commissures in an inhibitory manner. This arrangement together with a tonic discharge during rest allows afferent inputs from one labyrinth to influence vestibular neurons on both sides of the brain stem, even when peripheral inputs from one labyrinth are missing, and makes possible a push-pull organization between the two vestibular nuclei [7,8]. The push-pull behavior, however, is lost if one of the members of a SCC pair has lost function. Then, due to inhibitory cutoff when rotated toward the inhibitory direction of the remaining healthy SCC asymmetric VOR responses can be expected. This is known as Ewald's second law [9]. When corrected for the spontaneous nystagmus velocity significant dynamic asymmetries were present in most subjects, suggesting involvement of the horizontal, the anterior or the horizontal and anterior SCC combined on the lesioned side. In none of our patients did we find significant asymmetries when the posterior SCC on the lesioned side was excited. This suggests that the anterior and horizontal SCCs are involved in this disease to variable extents but that the afferents of the posterior SCC are usually spared.

In conclusion, this technique provides new insights into the functional principles of the vestibular system. After a unilateral vestibular lesion the response patterns showed a profound disturbance of the normal concerted action of the six SCCs. Our data confirm the earlier hypothesis that a vestibular neuritis must not lead to a complete unilateral vestibular lesion [10]. They extend our knowledge by adding that in general only the superior division of the vestibular nerve (including afferents from the anterior and horizontal canal and the utriculus) is involved.

ACKNOWLEDGMENTS

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The Flight Orientation Trainer (FOT) as a Means of Evaluation and Validation of Psycho-Physical Load on Flying Personnel

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SUMMARY:
Spatial Disorientation (SD) is a dangerous threat in aviation. In order to improve its training programs for SD, the German Air Force (GAF) procured the so called Flight Orientation Trainer (FOT). The system is described and first experiences based on a troop trial in 1994 with 22 experienced pilots evaluating profiles are presented.
Future aspects for the use of the FOT as a training aid and a scientific research tool are outlined.

1 INTRODUCTION:

Spatial disorientation has been a feared factor in the man-machine system since the beginning of aviation and often has been the cause of aircraft accidents. It occurs when a pilot takes an unreal situation for real. The sense organs responsible for spatial orientation are among other things the eyes, the vestibular organ and the sensors for proprioceptive stimuli.

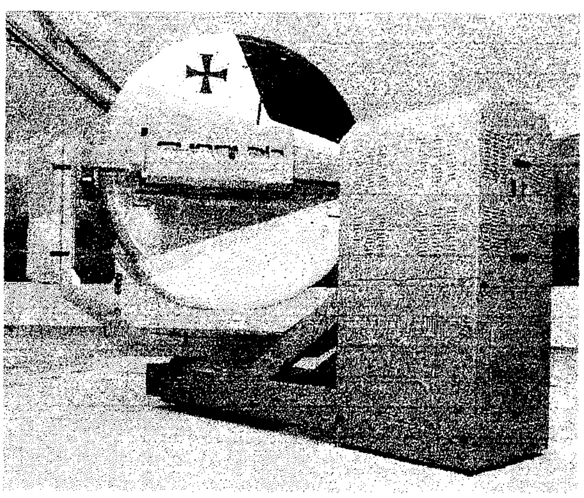

Figure 1: Flight Orientation Trainer (FOT)

Most important is the information provided by the eyes, and as long as this information corresponds to the other sensations, spatial disorientation will not occur.
However, during flight, situations may arise which cause the brain to misinterpret information coming from our sense organs. One of the result is what is referred to as "mismatch", which may lead to total loss of realistic spatial orientation.

Particularly insidious is spatial disorientation of type I which may lead to controlled flight into terrain. In this case, the pilot does not realize at all how dangerous his flight situation is until the accident occurs.
In order to prevent aircraft accidents of this kind, this phenomenon was explained in detail, both in theory and in practice, within the flight physiological training of pilot candidates of the GAF. Demonstrations using the old "spatial disorientation demonstrator" (SDD), which had been constructed and was operated by personnel of the Air Force Institute of Aviation Medicine, showed how unreliable our senses are, and how easily they can be deceived. However, the demonstrator had neither an instrument panel nor an artificial horizon. The student could not actively navigate, and complex patterns of movement were only possible to a limited extent, due to the design.
These were the reasons why we considered buying a new disorientation trainer. The Environment Tectonic Corp. (ETC) in the United States of America offered a series-produced model which was referred to as "Gyrolab".
After preliminary tests and information, procurement was initiated under the name of "Flight Orientation Trainer" (FOT).
During the acceptance test, varied responses were received from the members of the GAF / IAM. As a larger test group was desired to evaluate the FOT, a troop test was scheduled for the autumn of 1994.

2 SYSTEM DESCRIPTION:

Figure 2 shows a diagrammatic view of the Flight Orientation Trainer, which consists of the gondola, the roll-frame, the yaw-frame, and planetary arm attached to the central post. The gondola carries out the pitch motion.
The student sits in front of a concave mirror with a field of view of 120 x 40 degrees into which information about the environment produced by a computer is mirrored by means of red/green/blue projection. A virtual image is generated with a focus distance of 4 m. Below the mirror, a monitor shows the instruments for speed, flight altitude, flight attitude, engine performance and the nozzle position as well as the compass and the vertical velocity indicator for the climb and/or descent rate (VVI).

Paper presented at the Aerospace Medical Panel Symposium on "Neurological Limitations of Aircraft Operations: Human Performance Implications", held in Köln, Germany from 9-12 October 1995, and published in CP-579.

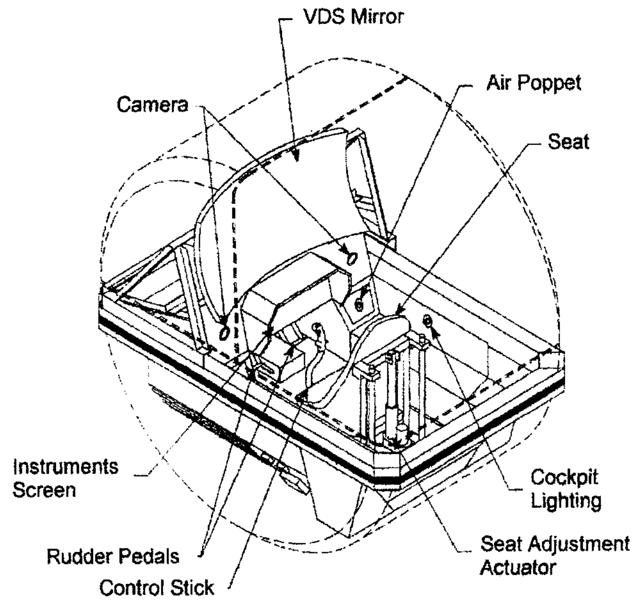

Figure 2: View of the cockpit, transparent view of the Flight Orientation Trainer (FOT)

The cockpit is equipped with the normal flight controls, stick, rudder pedals and throttle levers for engine control.

	Planetary	Yaw	Pitch	Roll
Motion	360° continuous, variable, and reversible	360° continuous, variable, and reversible	360° continuous, variable, and reversible	360° continuous, variable, and reversible
Maximum Acceleration, deg/sec²	15	50	50	100
Maximum Speed, rpm (deg/sec)	28 (168)	20 (120)	5 (30)	10 (60)
Minimum Speed, rpm (deg/sec)	0	0	0	0
Speed Range, rpm	0 to 32	-	-	-
Standard Control, rpm (deg/sec)	-	0 to 20 (0 to 120)	0 to 5 (0 to 30)	0 to 10 (0 to 60)
Subthreshold Control deg/sec	-	0,5 to 5	0,5 to 5	0,5 to 5

Operations and Maintenance Manual, German Air Force GYROLAB GL-3000-101

Figure 3: FOT drive specifications

The performance data are depicted in figure 3. Unlimited movement is possible about all 3 spatial axes and the so called planetary axis. The planetary arm can produce G forces of up to ±2.2 G which may act on the pilot in any direction.
The FOT is operated from a master control console. The crew to run the FOT normally consists of 3 to 4 persons, depending on the tasks.

In order to simulate realistic flight conditions, the FOT can be flown like a flight simulator in a so called "flight mode". There are, however, two fundamental differences compared with other flight simulators.
A unique characteristic of the FOT, in contrast to other motion systems, is the free movement about all spatial axes. Especially the yaw motion is a very important factor in many cases, where the senses are deceived.
Secondly, the FOT's so called "flight profile mode" makes it possible to store visual display and motion parameters in order to simulate situations which can be reproduced exactly.
Depending on the intended training purpose, the student can either passively experience this situation, or actively influence it like in a real flight, once control has been transferred to him.
The visual display and the instrument diplay can be modified externally, for example by changing the daylight conditions, by "freezing" the instruments or by selectively "blacking them out".
In another mode, the so called "ground profile mode", the patterns of movement are developed using a "profile editor".

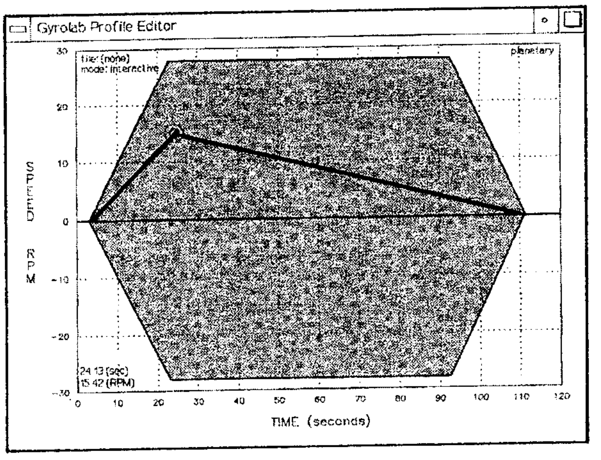

Figure 4: Screen display during profile development

Figure 4 shows the screen displays needed for this purpose. There are two profile modes available to the FOT user. Ground Profile mode (GP), and Flight Profile mode (FP).
In GP mode, a motion profile is created using an off-line procedure. The motion of all four axes are fully programmable, using a software tool with time versus velocity scale, a kinematic force calulator, and a profile motion preview capability. The finished motion profile is replayed for the student in sync with a recorded "out-of-the-window" visual scene. This visual scene can be developed by the user to match the motion profile, or to create a mismatch on purpose.
The control transfer, from the recorded GP to student control is a preprogrammed parameter, on an individual axis basis. At this control transfer time, the student can use the standard cockpit equipment to control the velocity of the axes. The visual scene will follow the student's input after the point of control transfer.
For example, if the student presses the control stick to represent a Roll left command, the gondola will actually roll in a left direction, and the visual scene will display an appropriate image. his control is a sensitive one, and the student can

easily create a too great a motion. An inexperienced student is likely to over-react.
This limitation in the pilot's control results in the GP mode being quite useful for the demonstration of spatial disorientation, but less useful for evaluating his ability to correct the attitude of the aircraft.

FP mode operates differently than GP. In FP mode, the pilot's inputs are sent to a separate computer, the "aeromodel" computer. Here the pilot's control inputs are fed into a program which calculates the response of a real aircraft in real time. This set of gondola positions and acceleration forces are then implemented by the motion base. Because the pilot's inputs are implemented by a "real" aircraft, the response of the FOT's motion and visual are always appropriate.

To make a FP recording, a "script" is written, defining the flight path required to give the student the desired experience. This "script" is then "flown" by an expert pilot in the FOT. The entire flight of the expert pilot is recorded by the FOT computer system. This flight can be replayed for a student pilot, at will.

The control transfer, from the recorded FP to the student control, is done using a control button at the operator's console. The control transfer point is chosen by the Physiological Training Officer (PTO), based on that particular profile's characteristics, and the response that the PTO sees and hears from his student in the cockpit. The student has complete computerized control of the aircraft after the control transfer.

This FP mode is useful for evaluating the students ability to correct the attitude of the aircraft, after being subjected to the inputs in the profile.

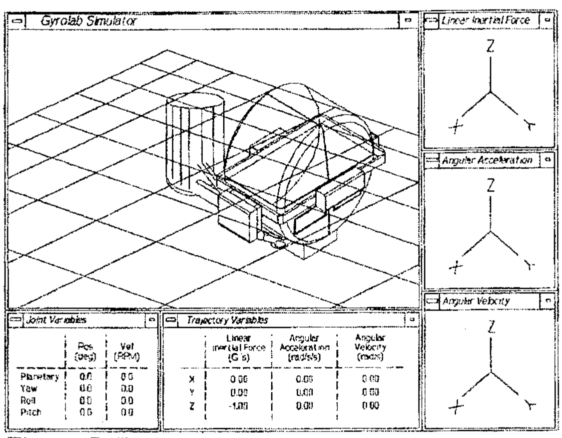

Figure 5: Picture of vectors

3 METHODS AND TEST RESULTS:

During a troop trial in the year of 1994, training profiles were tested and evaluated by a total of 22 pilots. 8 of those were jet pilots, 12 were helicopter pilots and 2 were pilots of transport aircraft.

The helicopter pilots of the Federal Armed Forces are an inhomogeneous group, both with respect to their training and their flying qualifications. Navy pilots who fly the "Sea King Mk.41" aircraft type, for example, start training on fixed-wing aircraft and switch later to helicopters. Pilots of the UH-1D and BO 105 VBH (liaison helicopter) however, train on helicopters from the very beginning.In contrast to above mentioned Navy pilots they normally are only VFR-rated, in spite of having logged up to more than 5,000.

The troop trial was to answer the following questions:

- Are the planned illusions produced sufficiently clear by the FOT?
- How realistic are these illusions on the background of the flight experience of the pilots testing the FOT?
- To which extent is it possible to recover, that is to fly out of a situation recognized as dangerous

With the help of questionnaires and debriefings the pilots were asked to evaluate cockpit, take-off behavior, maneuverability, landing characteristics, visual display, etc.

Figure 6 shows which grades were given. The grades were given in accordance with a prescribed pattern, that is ranging from 1 to 4 for how realistic the simulation was and from A to D for "recovery". "NE" stands for "not evaluated" in cases where the pilot has not tested the respective profile, for example if the profile was developed in the course of the troop trial or if a comparable profile was tested.

Realism		Recovery	
- very realistic	=1	- unlimited recovery	=A
- minor deficiencies	=2	- limited recovery	=B
- major deficiencies	=3	- deficient recovery	=C
- unrealistic	=4	- impossible recovery	=D

NE
- not evaluated

Figure 6: Diagram of grades

Before the actual test phase began, the test pilots had a "familiarization flight" of 15 to 30 minutes to get accustomed to to the equipment and to get rid of fears they might have had.

During this flight maneuvers as turns, landing approaches, rolls, etc. and the numerous options for entering disruptive factors such as fog, turbulences, changes in daylight conditions, etc. were evaluated.

The reviews were conducted in blocks after each group of interrelated subjects (for example, visual illusions during landing approach). During the tests, the spontaneous comments of the pilots were recorded in writing.

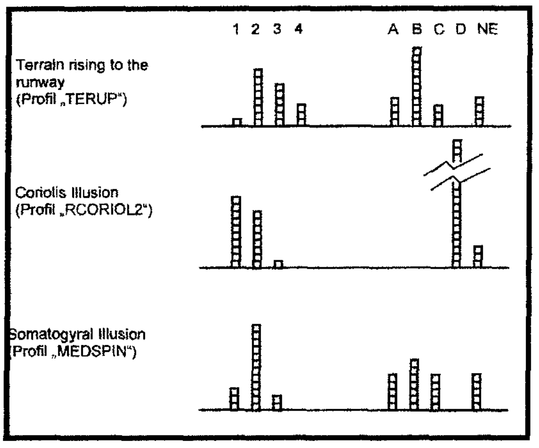

Figure 7: Examples of evaluation during the troop trial

Figure 7 shows the gradings for some typical profiles:

A) "Terrain up illusion":
This illusion is caused by rising terrain and leads to shallow approaches. Because the visual display in the FOT is not sufficient, the effect is inadequate. The illusion itself does occur in reality, and in the FOT it is possible to fly out of this situation once it has been recognized.

B) "Coriolis illusion":
The desired effect is achieved; the profile (not the illusion!) does not have relevance to actual flight since the pilot sits in the dark and is turned about the vertical axis without his senses noticing it. The desired effect is produced by movements of the head. It is not possible to hand over control to the passenger in the gondola, therefore the "recovery" is rated "D".

C) "Somatogyral Illusion":
The effect is produced in a typical flight situation: the "spin". The handover of control is possible.

4 RESULTS:

The result of the troop trial can be summarized as follows:
Isolated vestibular illusions are produced very well whereas some of the visual illusions are considerably limited, due to the poor performance of the visual display system.
Training in the FOT was regarded as desirable and useful by the "test pilots", but only after a previous flight experience of about 20 hours to be able to handle the controls and to understand the situation. However, this is only necessary if the flight profiles are used. This flight experience is not needed to demonstrate simple illusions for which active cooperation of the gondola passenger is not required. Jet pilots whose routine included IFR-missions stated, that further training sessions in the current form were not necessary after completion of their training. The helicopter pilots, especially those without IFR ratings, were very interested in further demonstrations of possible illusions, even if their flight experience amounted to several thousand flying hours. At present, improvements are being fielded within an "enhancement contract", based on suggestions resulting from the troop trial.
There are only two more devices comparable to the FOT (in the United States of America and in Japan). They also are in the introduction phase.
Except the troop trial and a experience exchange with the USAF, there is little experience how to use the device best, and which training results actually can be achieved.
Possible "side effects" of rides in the FOT are also not sufficiently known. During the troop trial, there were two cases of "simulator sickness", which lasted several days in one case. To date the causing factors for this simulator sickness is not sufficiently known, as far as the FOT and its counterparts are concerned. These causes must be found and be considered in the development of new training profiles. At present, we are developing programs for the FOT in cooperation with other divisions of the German Air Force Institute of Aviation Medicine, for example for pilot candidate selection, the anti-airsickness training program and aircraft accident analysis; the latter field is still in the planning stage.
The generation of visual illusions and the occurring subjective and objective response patterns require thorough evaluation and validation.

Figure 8 shows the outline of planned investigations psycho-physical stress in the FOT.

1. Kinetic Stimulus

	Speed	Acceleration
1.1 Pitch Axis	30°/s	50°/s²
1.2 Roll Axis	60°/s	100°/s²
1.3 Yaw Axis	120°/s	50°/s²
1.4 Planetary Arm	168°/s	15°/s²

2. Optical Stimuli

3. Acoustical Stimuli

4. Combination of 1.-3.

5. General Stimulus-Reaction-Tasks

6. General Mental Tasks

7. Flightspecific Mental Tasks

8. Combination of 1.-7.

Figure 8: Investigation of psycho-physical load

There is the possibility of creating multimode types of stress by combining motor stimuli, optical, acoustic and mental tasks which are combined freely and may lead to extremely complex responses.
Physiological data are mainly cardiovascular and neurophysiological but also endocrinological and immunological parameters.

1. Cardiovascular

- Electrocardiogram (ECG)
- Respiration
- Bloodpressure
- Oxygen-Saturation

2. Neurophysiological

- Electroencephalogram (EEG)
- Electrooculogram (EOG)
- Electromyogram (EMG)

3. Endocrinological

4. Immunological

Figure 9: Physiological data

As a result of the troop trial, the FOT has to be evaluated in more detail, concerning its use as training device, profile test-bed and scientific research tool. Points of interest in the near future will be:

- training profile developement
- refinement of SD-training concepts
- implementation of helicopter-controls and -flight characteristics
- feasibility studies for lower-cost/capaility SD-trainers
- integration of physiological monitoring equipment
- developement of data-interfaces for scientific requirements

In contrast to real flight, the kinetic, optical, acoustic and mental stimuli that can be demonstrated and simulated using the flight orientation trainer, and can be standardized and reproduced. As a result, the trainer may be used as follows:

- Demonstration of the function of the vestibular system below and above perception thresholds.
- Complex combinations of sensory stimuli using kinetic, optical, acoustic and mental signals.
- Possibility of recognizing and responing to dangerous situations which might lead to spatial disorientation.
- At present, the effects of movement profiles can only be evaluated by off-line analysis the results of which could be used for scientific, medical and psychological applications.
- The following may be conducted with the already proven capabilities of the FOT:

- Demonstration of spatial disorientation phenomena for flying personnel and pilot candidates.
- Demonstrations for students during training courses.
- Flight-physiological training within the framework of the anti-airsickness training program (AATP) for desensitisation in the case of airsickness of student pilots, mission-ready pilots and crew members.

- Research projects in cooperation with other institutes and universities are planned.
- First of all, experienced pilots are required for the evaluation of the effect and in order to develop profiles for future training prorams. The objective of the training is to give aircrew members the knowledge to recognize, analyze, counteract and prevent spatial disorientation, particularly of type 1, that is the "controlled flight into terrain", thus minimizing the number of cases where the human factor is the cause of an aircraft accident.

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MEG and EEG Recorded In Complex Multitasking Environments For The Classification Of Human Performance

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One of the most important observations that William James made is that consciousness- the awareness of information - is comprised of continuous and successive processes , that consciousssness is a stream of events, and as such, the time domain of this stream must be understood.

It is now clear that although the processing of information may be observed within some discrete interval of time, it necessarily depends on the previous processing of similar or identical input - memory always plays a role (Loftus, 1979).

Identical or similar input, to that previously experienced, does not necessarily mean that the processing of that input is similar or identical.

Insofar as the brain is concerned the processing of each input includes not only the memory of previous inputs, but also those endogenous modifications imposed by the brain that are necessary for the final product, i.e., the conscious event, "make sense", that is, to make the product consistent with the context in which it occurs, both historically and in the present.

Memory is always a construction of the past, the present, and predictions of the future. Furthemore, it is now obvious that the brain of each person is an individual brain. The same brain may process the same input differently at different times, depending in part on previous experience, but also in part on its inherent capability do so - that is the inherent capability of the brain for variability - what characterises brains is not central tendency but variability (Edelman, 1989).

Hebb's theory of cell assemblies and phase sequence was an important concept, in the sense that the attempted to direct the thinking of neuroscientists into an explanation of complex behaviour by using neurophysiological constructs. Learning and memories were identified as the organisation of neurones resulting from their exposure to the temporal association of synaptic function - now called the Hebb Rule. More recently Edleman has developed another approach, the Theory of Neuronal Group Selection (TNGS) - one which shows promise as a conceptual method for thinking about complex neurophysiological systems within both the domains of time and space. Edleman believes, and rightly so, that the brain, "in adapting to an unlabelled world full of novelties...act(s) by a process of selection upon variance rather than by instruction.

One of the most important attributes of the nervous system is frequently ignored - its dynamic properties with respect to both space and time (Edleman, 1989).

If feedback occurs - as it does for example in cortico-thalamic-basial gangia-cortex planning of visuo-motor co-ordination - then an index of that re-entry - as it is occurring in the brain during information processing, could give a measure of the effectiveness of that processing. A good deal of evidence points to spontaneous activity in the high gamma range as and index of re-entry (Llinas, et al., 1992a,b) . Most behaviour of the kind we are studying - memory, perception, motor planning and performance - is defined with observations that are sufficiently broad in scope - compared with the molecular systems of the brain responsible for the behaviour.This is why variability of those systems is commonly ignored - considered the result of noise or randomness. For example, the observation of a reaching movement, precise though it may be, is described at a much more molar level than the synaptic, axonal and muscle fibre system changes that are involved. The molecular observations can be quite variable but can nevertheless be seen as resulting in the same output

The brain may do the same thing in different ways at different times. Indeed, it can be argued that variability in neuronal systems are the norm and our assumptions of the constancy of underlying processes is nothing more than a limitation of our capability for observing the consequences of that variability.

Paper presented at the Aerospace Medical Panel Symposium on "Neurological Limitations of Aircraft Operations: Human Performance Implications", held in Köln, Germany from 9-12 October 1995, and published in CP-579.

A new approach is needed - the study of normal behaviour - behaviour that is occurring in realistic environments - behaviour that is variable and complex, behaviour that requires parallel processing of complex inputs.

Concept of Multitasking: In the past several years it has become increasing clear that the study of information processing in complex environments must include an analysis of functional brain systems when several tasks interact in the way they almost always interact in normal learning and performance. memories and performance systems are always changing as the result of endogenous processes within the brain that are not time locked to immediate stimulus input - or to response output.

As input courses through the brain (and spinal cord) complex feedback circuits come into play - particularly at cortical levels resulting from the interaction between cortex and nuclei of the thalamus and basal ganglia. During the course of this feedback, the characteristics of the information being processed may, from the brain's perspective, be significantly changed.

Since the nature of complex information processing usually requires time on the order of tens of milliseconds (e.g., reaction time for most visual discriminations is usually on the order of 100 msec) direct measures of brain function responsible for processing has generally proceeded along two lines: electrical activity that is time locked to input within about the range of about 50 to 5000 msec after input, or brain electrical activity that is spontaneous, i.e., not necessarily time locked to the input.

These two approaches rest on different assumptions about how the brain processes information

If one assumes that processing is time locked to input then signal averaging is a reasonable way to extract the signal from background activity (noise) that is not time locked to the input. However, if one assumes that processing of the information may have a variable time course after each input - resulting from, for example, the retrieval of memories that are updated after each input - then signal averaging or other analytic methods that assume time invariance of the signal, are not appropriate. It is clear from known neurophysiology that both time locked and non-time locked processing is occurring in the brain.

For example, recently we have shown that using methods of analysing activity time locked to the initiation of a voluntary movement (activity preceding the movement) it is possible to predict whether right or left finger movement is going to occur before it occurs.

However, analysis of non-time locked activity has also been very fruitful in predicting what might be called "brain states", i.e., the readiness of the brain and its capability for processing information. This concept underlay the multitasking environment developed for the selection, assessment and training of Air Traffic Controllers, which I would like to discuss shortly.

If it is important to assess the capability of the brain to process and to acquire information then it is necessary to separate the input, central processing and output functions of the brain. For example, if there are deficits in output (performance) it could be attributable to deficits in the input, problems with the capability of the brain to process, or deficits in the (motor) output. Simply measuring performance does not enable a discrimination between these. . The reasons for the deficits will of course determine whether it is possible to overcome those deficits and the nature of the training that may be required - and of course this information could be used for assessing the cost effectiveness of strategies used to identify individuals with differential capabilities to process different kinds of information. The goal of this research is to develop methods for best using the human resources in ways that are best for individuals.

Neural Net analysis of 40 Hz cortical activity in multitasking: The ATCMT (Air Traffic Control Multitasking) procedure is one in which the subject must perform four tasks simultaneously. After an extensive task analysis the tasks were designed to require information processing relative to two dimensional spatial memory, memory for rates of movement, continuous monitoring tracking and control of moving objects, the use of two dimensional representation of three dimensions, and the continual monitoring and maintenance of temporally ordered events (see Fig. 1).

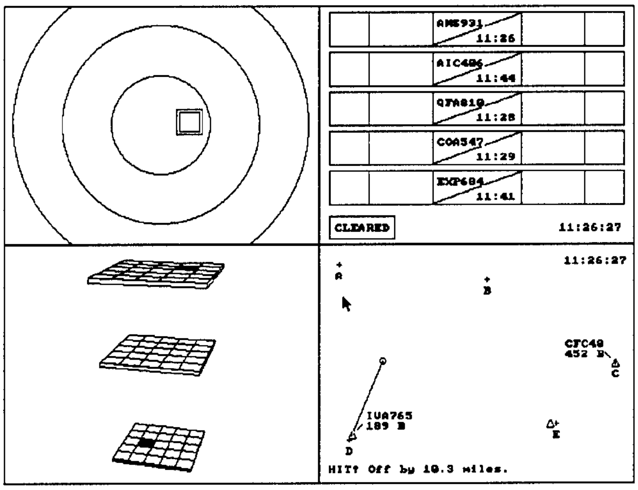

Fig. 1. Air Traffic Control Multitasking

In this program the subjects establish their own priorities and strategies for maintaining their best level of overall performance. The program is configured such that several variables in each of the tasks may be set to make that task more difficult. Based on a further analysis of the data the program is now being configured to automatically adjust the level of difficulty as a function of performance. Several performance variables are measured for each task and an algorithm has been developed to best compute an interaction between output variables that distinguishes between different levels of training and is intended to predict success in air traffic control and facilitate training in a particular and crucial stage of the Air Traffic Services training programme. In the development of the program direct measures of brain function were recorded in a group of experts drawn from four different regions of Canada and from the training staff of the Transport Canada Training Institute.

Groups of naive subjects drawn from Simon Fraser University in Burnaby, B.C., and two groups of trainees at TCTI were also studied, one entering the Transport Canada training programme and a group that had passed the critical stage of moving from classroom training to the application of that training in simulators.

Development of the multitasking environment required almost two years of design and redesign resulting from testing iterations at different levels of training and performance.

Measures of Brain Function: Several elements in each of the tasks were used to trigger collection of Electroencephalographic data. Initially we utilised a configuration of 19 electrodes, however, as part of the requirements of the study we have been able to reduce that number to 12 channels. A back propagation neural net analysis of the EEG using data that has been transformed to the frequency domain, extracting the power of high gamma frequency bands (35 - 45 Hz) and combining that power of those bands over space (across channels) and time, over an interval preceding and following selected events in the tasks. This high gamma activity has been studied as an index of information processing (Singer 1993).

The data was used to train the Net using a standard back-propagagation architecture configured with 12 inputs, 3 hidden nodes and 2 output nodes. In order to insure the Net was in fact training on a true difference between experts and controls a reliability test was performed.

One expert's data was removed completely from the training process and the net was trained again. Once the Net had been trained without this subject that subject's data was used to test the net. The network was able to identify this subject as an expert over 76 percent of the time. The training data was then mixed up so that experts and controls were randomly assigned to a training group and the net was trained again. Once the net had been trained the same testing data was reintroduced for classification. For the first of these tests, accuracy did not surpass a level of approximately 65% and on the second test it did not exceed the 50% level. This procedure confirmed that the Net did not train an arbitrary difference that could have been found in any combination of data thus insuring that the Net was distinguishing expert controllers from controls.

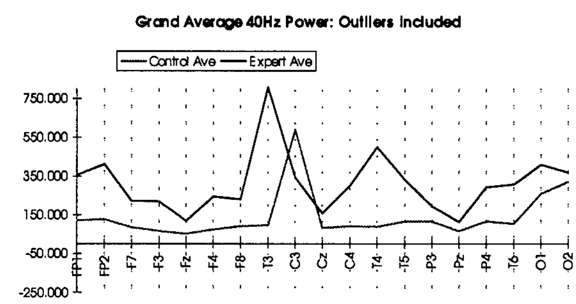

Fig. 2. 40 Hz Density For Experts and Controls

Error	Control	Expert	Total
0.99	88.39%	86.25%	87.58%

Table 1: Correct Classification By Neural Net

The behavioural results were also computed using an algorithm that combined all performance measures with respect to time and with respect to several measures performance in each of the tasks. These were established with the following algorithms:

Box Task:
4 / ((Average Age / Average Number of Steps for small box to get out of large box (= 7.5)) / Total Run Time (minutes).

Sectors Task:
10 X (10 - (100 / (((Hits + 1) / Run Time) + (Run Time / Misses + 1)) X (Hits + Misses)))

Data Strips Task
100 - (10 X ((Number of Violations / Number of Flights)) + Average time to Clear / Total Run Time).

Tracking Task
100 X (((Hits + Correct Rejections) / Hits + Misses + Correct Rejections + False Alarms)) - (Average Distance Error / 25)).

It can be seen from the behavioural results(Fig. 3) that the two parts of the multitasking environment in which the experts do better than the controls are the strips task and the tracking task. In one task the controls do better

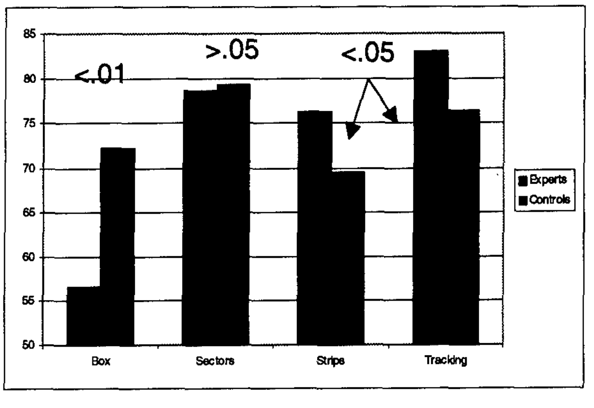

Fig. 3. Behavioural Results

than the experts, the box task. Thus, although the behavioural measures are important in discriminating between experts and controls the EEG utilised in conjunction with neural net analysis discriminates equally well if not better. The 40 Hz measure is probably related to overall concentration on the tasks and the ability of experts to rapidly shift their attention to the strips task and focus attention to that task when the shift occurs.

Another complex environment in which EEG and MEG has been used to analyse information processing is one we designed to study the effect of sleep deprivation on planning to control a moving object. As the result of discussions with the U.S. Department of Transportation and the Canadian Transportation Development Centre ABBS was asked to develop a paradigm for using EEG and MEG to measure the effects of sleep deprivation . It was agreed that the paradigm would attempt to utilise requirement for information processing that were similar to those used by locomotive engineers.

The paradigm designed had the following general attributes: The subjects were required to stop a "train" precisely on target. The train proceeded along a pre-designated track, at a predetermined velocity and with a predetermined inertia. Stopping the train was accomplished by pulling-back on a joy stick. Each position of the joystick reduced the speed of the train by a prescribed amount, determined by the velocity and the inertial of the train. The response of the joystick was designed such that the train could not be speeded up by pushing the joystick forward. Therefore the subject was required to plan the sequence of joystick positions that would stop the train exactly on target as "smoothly" as possible. Smoothly was defined as a gradual and uniform slowing until the train finally stopped on target. For each trial the train was started by the experimenter. The intertrial interval was varied by the experimenter between 5 and 60 seconds. The subject heard two tones, a high tone and a low tone, separated by 1.5 seconds after the train was started. The "place along the track" when these two tones occurred was randomised within predetermined limits. The first tone was a "get ready" signal. The second tone signalled the subject to press a button press a button on top of the joystick and then to begin stopping the train by pulling back on the joystick (fIg. 4).

In this experiment we were looking for two types of effects: the result of sleep deprivation on the Contingent Negative Variation (CNV) and on the 40 Hz spectral component in the same interval. The first, the CNV is a measure of the degree to which the subject is preparing for the response, the second is a measure of the dynamic

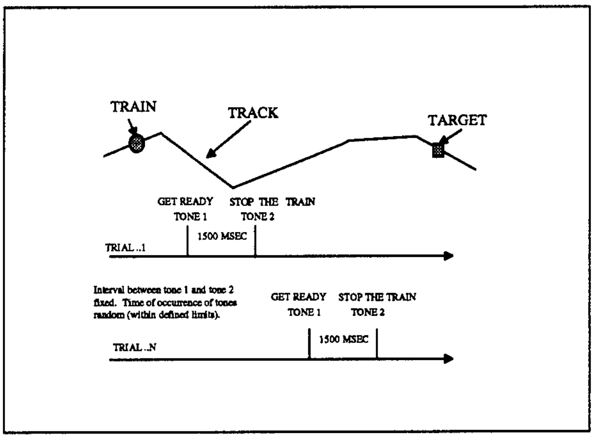

Fig. 4. Choochoo Configuration

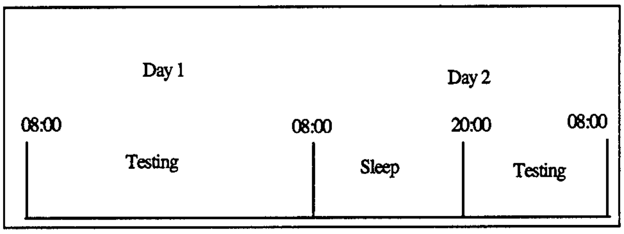

Fig. 5. Sleep Deprivation Schedule

poperties of that preparation (Naatanen, 1990). The sleep deprivation and work schedule we used is summarised in Fig. 5.

The paradigm was one that produced a classic CNV between the get ready signal and the imperative stimulus that signalled the response of stopping the train. Initial runs resulted in generally a greater amplitude CNV than did the later runs in the same day - in the second day the overall amplitude of the CNV was less, and finally lowest at the end of the second day. This is consistent with the interpretation that there is a reduced capability of processing the information necessary to plan the response as sleep deprivation proceeds and that the effect can be seen in one day of work. (Fig. 6).

In order to study the dynamic characteristics of the planning interval additional studies using MEG were carried out in which subjects were subjected to exactly the same conditions as in the EEG study however the work periods intervening between recordings in the Choochoo environment was with ATCMT .

Using MEG we recorded the interval during which the subject was getting ready to make the movement in the Choochoo paradigm and computed the density of 35 - 45 Hz in that interval by taking the difference between the 40 Hz density in the resting condition and in the preparation condition

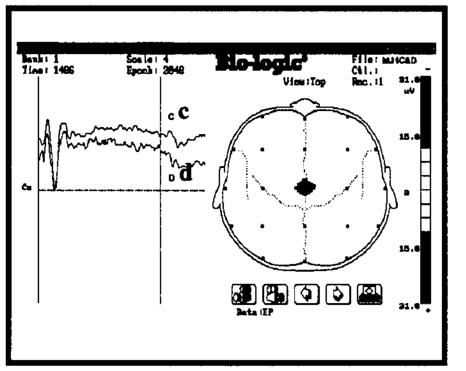

Fig. 6. CNV Before Sleep Deprivation first and last run of day 1 (c, d).

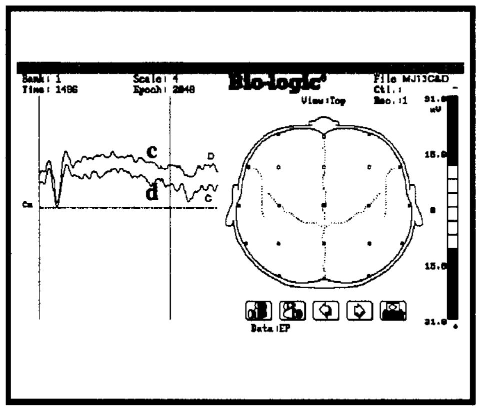

Fig. 7. CNV After Sleep Deprivation first and last run of day 2 (c, d).

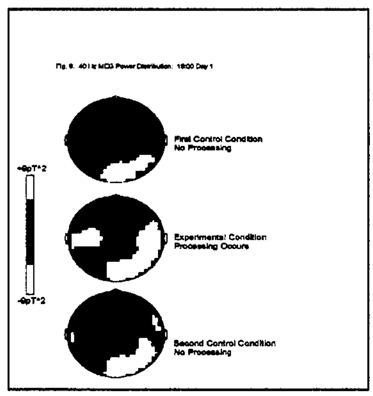

Fig. 8. 40 Hz MEG Before Sleep Deprivation 16:00 of first day

As sleep deprivation increased there was an overall reduction of gamma activity in both the control and processing interval, however this occurred to a greater extent in the processing interval. After the first night of work there was some recovery of 40 activity at

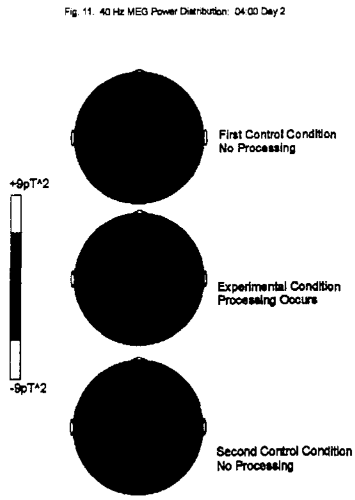

Fig. 9. 40 Hz MEG After Sleep Deprivation
04:00 of Day 2

noon of the next day. This gamma activity was primarily from temporal sensors. When the density differences were plotted for only those sensory during the second night of deprivation it can be seen that the reductions were evident a about 22:00. and from about 0400 to 0600. The interval between 10:00 and 04:00 showed some recovery, particularly around noon - however there were differences between subjects as to exactly when that recovery occurred. Behavioural control, measured as changes in velocity of the train and the braking action were predicted by the MEG in respect to the ability of to smoothly stop the train on target.

What Do These Experiments Suggest?

- Direct measures of brain function may be able to index the capability of individual performance in complex environments where many variables are interacting.
- Direct measures of brain function may be useful as a method of giving to individuals a knowledge of when performance or alertness may deteriorate.
- Direct measures of brain function may be useful in the selection of the personnel for the types of information processing required in different environments.
- Direct measures of brain function may be useful for the training of personnel when transitions between different modes of information processing are required.

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Response Latencies to Aircraft Detection Among NORAD Surveillance Operators

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A function of North American Aerospace Defence (NORAD) in North Bay, Ontario is to identify all aircraft entering Canadian air space. The first step in performing this task is to detect visually the presence of aircraft from either radar or transponder information presented on display consoles. This challenging, real-world vigilance task was used in two experiments to investigate factors affecting detection latencies. Taken as a whole, the experiments revealed that 1) transponder tracks, with their unique symbology, were more easily detected than radar tracks; 2) performance varied as a function of geographic area of coverage; 3) the midnight shift was particularly sensitive to vigilance decrements; and 4) a 'vigilance decrement' effect can occur in a real world task, but this effect is not as strong as those reported in laboratory studies.

1. INTRODUCTION

Numerous vigilance researchers have questioned the wisdom of generalizing laboratory results to real world tasks [1, 2, 7, 11, 13, 20] Their concerns arise mainly from three observations: 1) laboratory vigilance tasks rarely resemble their real world counterparts; 2) when real world tasks are adequately simulated the results often differ from laboratory findings; and 3) there are "...few, if any, troublesome vigilance decrements in the operational tasks of the real world" [1, p. 737]. While admitting that a large body of important psychological knowledge has accrued from laboratory vigilance research, Wiener [22] also cautions that vigilance must be studied in more complex and operationally valid environments. He notes that real-world vigilance tasks usually involve highly trained and experienced individuals working long hours on critical tasks with relatively low signal rates. Unfortunately, conducting research in such environments, without impeding or disrupting ongoing activity, is often very difficult. Measurement techniques need to be non-intrusive, experimental protocols must be consistent with the demands of the workplace and the results have to be relevant (and helpful) to the individuals begin studied.

We have had the opportunity to study such a real world vigilance task (not a simulation) under daily operational conditions, with control over several factors. One function of North American Aerospace Defence (NORAD) in North Bay, Ontario is to identify all aircraft entering Canadian air space. This is accomplished by: 1) visually detecting potential intruders from either radar or transponder information presented on display consoles; and 2) correlating the detected targets with logged aircraft flight plans. If the targets do not correlate with logged flight data, then interceptor aircraft may be scrambled to visually identify the transgressor. Since the entire process is dependent upon rapid initial detection by the surveillance operators, it is important to have a good understanding of the factors influencing detection performance in this operational environment.

[1] A shorter version of this paper will appear in the Human Factors Journal (Sept '95)

Paper presented at the Aerospace Medical Panel Symposium on "Neurological Limitations of Aircraft Operations: Human Performance Implications", held in Köln, Germany from 9-12 October 1995, and published in CP-579.

1.1 The Air Surveillance Task and Environment

Canadian NORAD Region's air surveillance has been continuously maintained for 35 years and involves monitoring returns from an array of radars covering Canada's east, west and northern territories. The radar information is data-linked to Canadian NORAD Region headquarters in North Bay. Canada's area of radar coverage is divided into two geographic regions, the surveillance of which is given to two separate squadrons (see Figure 1). The squadrons are physically, functionally and operationally independent. They each have their own equipment, personnel schedules and are located in different areas of the NORAD facility. Although they are responsible for different geographic regions, Canada's radar picture is available to either squadron in the event of an emergency.

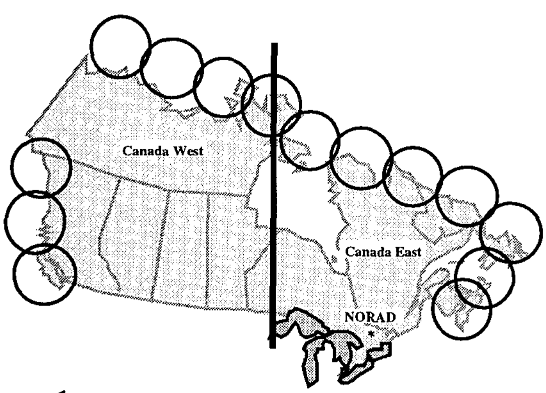


Figure 1: NORAD radar coverage of Canada's geographic perimeter. Neither the number of the radars nor their locations is accurately depicted.

Each geographic region (i.e., Canada East or Canada West) is subdivided into zones that are displayed on individual surveillance consoles. The display consoles are round, monochrome (green phosphor) and vector scanned. Air surveillance operators do not monitor returns from individual radars; they monitor returns from geographic zones that are serviced by multiple radars. The entire air picture is updated every 12 seconds by NORAD computers which must fuse and correlate all radar data to eliminate redundant echoes reflected from adjacent radar sites. To represent aircraft movement, the 7 most recent radar returns are sequentially displayed every 2 seconds. This leaves a 'blip' trail showing an aircraft's heading and speed.

The surveillance operator's task is to detect these tracks and direct the computer to tag and assign track numbers. [NOTE: The operators are not responsible for identifying the tracks, only for detecting them.] Depending on the type of aircraft and its intention, a track can have one of two 'signatures'. Aircraft equipped with transponders emit status and identification signals that are received by the radars and are displayed on NORAD consoles with a 'diamond' symbol. Such tracks are referred to as 'beacon' tracks. Aircraft without transponders can only be detected by search radar. Their symbol, a 'hyphen', is identical to all other spurious radar returns (e.g., noise or clutter caused by storms, sea spray, mountains, etc.) and are more difficult to detect. These tracks are referred to as 'search' tracks.

In order to assess detection performance, a method was needed to measure response latencies of surveillance operators over long periods. This was accomplished by taking advantage of the capability for NORAD's computer system to inject simulated tracks over the live air picture. When displayed on the surveillance operator's console the simulated tracks are indistinguishable from live traffic. Simulated tracks can be given either the 'diamond' (for beacon tracks) or 'hyphen' (for search tracks) symbol and can be allocated precise speeds, headings and altitudes. Both the time a simulated track first appears on the console and the time it is detected by the surveillance operator can be recorded. This allows response times (RT) to be calculated and analysed. Unfortunately, due to inherent system limitations, RTs cannot be computed for live air traffic.

To assess the impact of performing vigilance studies on NORAD operational efficiency, a short pilot study was conducted [4]. During a 48 hr period, 10 simulated tracks per hour were injected into Canada East's (live) airspace. Eighty percent of the 480 simulated tracks were given search track symbols and 20% beacon track symbols. The results indicated that RTs were slower for the detection of search tracks than for beacon tracks. Due to the differences in symbology this result was expected. Also, RT for search tracks was slower for the

midnight shift than for either the day or afternoon shift; RTs for beacon tracks yielded no differences.

The present paper describes two experiments. The first is an extension of the original pilot study [4] investigating the effects of track type (i.e., beacon vs. search) and surveillance shift (i.e., evening vs. midnights) on detection times. The second study varied coverage area and time-on-task. Both experiments were conducted in the Canada East region because of its higher level of air traffic — i.e., the North America - Europe air corridor.

2. EXPERIMENT 1

The initial pilot study [4] demonstrated the feasibility of injecting simulated (aircraft) tracks over live air traffic during day-to-day operations. Experiment 1 was designed to extend these findings by collecting a larger, more representative data set.

2.1 Method

2.1.1 *Subjects*

Sixteen surveillance operators, each with hundreds of hours of logged console time, served as subjects for this experiment. They were informed as to the purpose of the study and were assured that individual performance results would not be released to their superiors. Since the subjects were fulfilling their regular work duties they were not given monetary compensation for participating in the study; however, the subjects were promised a briefing of the final results and they all expressed interest in the study.

2.1.2 *Procedure*

The experiment was conducted on two occasions separated by one month. On each occasion the subjects had recently finished three days of leave and were beginning three consecutive days of either an evening (1500h - 2300h) or midnight (2300h - 0700h) shift as part of their regular duty cycle.

On the first day of each experimental run, prior to the beginning of their shift, the subjects were briefed about the purpose of the study. Although they were informed that simulated tracks would be mixed in with the live traffic, they were given no information concerning frequency or location of these tracks.

For the evening shift the Canada East region was divided into 5 surveillance zones (i.e., consoles) whereas for the midnight shift 4 zones were used. During both shifts the subjects followed a typical work/rest cycle of 45 minutes on scope and 30 minutes rest. The subjects rotated through each console.

Before the experiment, a computer program was written to generate a list of the random stimuli to be manually entered into NORAD's computer during the study. Twenty-five simulated tracks per hour, randomly spread over the 5 (evening shift) or 4 (midnight shift) geographic zones were produced specifying each track's time of appearance, speed, altitude, zone placement and track type (i.e., search or beacon). In total, 2400 simulated tracks were presented (25 tracks/hr x 8hrs/shift x 2 shifts x 6 days) of which 60% were radar and 40% were transponder. Four experienced airforce personnel working in a different area of the NORAD facility used the stimulus list to inject the simulated tracks at the appropriate times.

Since the entire NORAD air picture of detected tracks is continuously recorded on magnetic tapes, we were able to retrieve and generate two result files: 1) the time of appearance for each simulated track and 2) the time of detection for all tracks (simulated and live). We then paired the appearance and detection times for each simulated track and subtracted one from the other to obtain response latencies.

2.2 Results

Forty-six percent (1105) of the 2400 simulated tracks presented to the surveillance operators were lost due to a software problem in the data reduction algorithms — a problem corrected for Experiment 2. Most of the lost data were from days 2 and 3 of the second experimental session. As a result, only 490 (38%) beacon and 805 (62%) search track response latencies were analysed.

Frequency distributions of RT data are typically positively skewed and must be transformed before statistical analyses can be performed. A $\log_{10}$ transformation [19] was applied to the data which resulted in: 1) normally distributed data, and 2) geometric means (i.e., antilogs) in original units of measurement (see Figures 2 and 3). To

remove the influence of outliers in the transformed data, reaction times greater than ± 3 interquartile lengths (i.e., 3 x the range between 25% - 75%) from the mean were excluded from further analysis. This procedure was performed separately for the beacon and search data distributions, and yielded the exclusion of 2 beacon and 4 search scores.

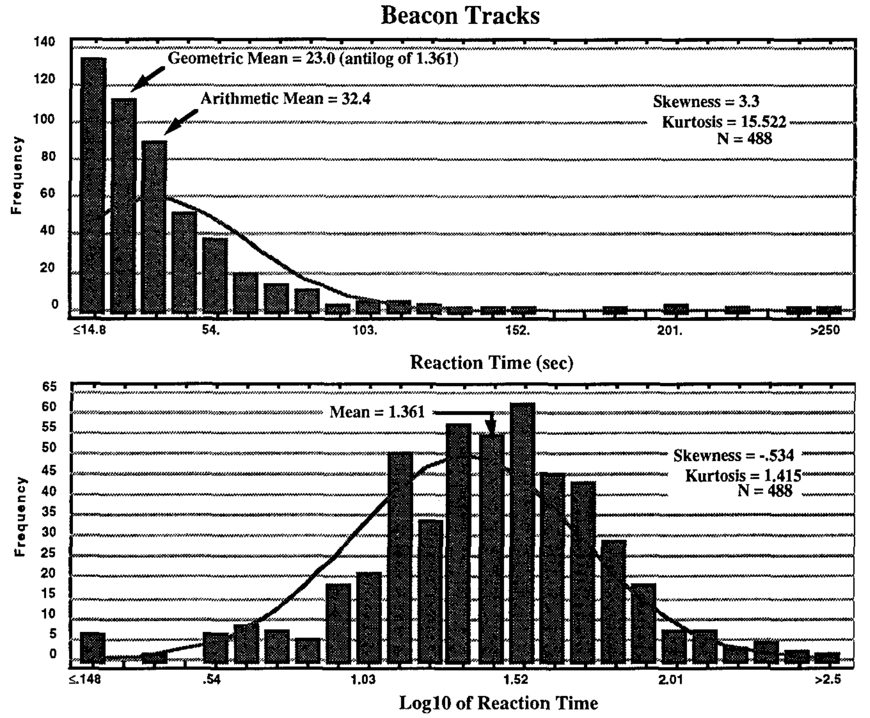


Figure 2: Frequency distributions of detection times to simulated 'Beacon' tracks. Top figure illustrates the positively skewed raw data; bottom figure illustrates the normalized (log10) transformed data.

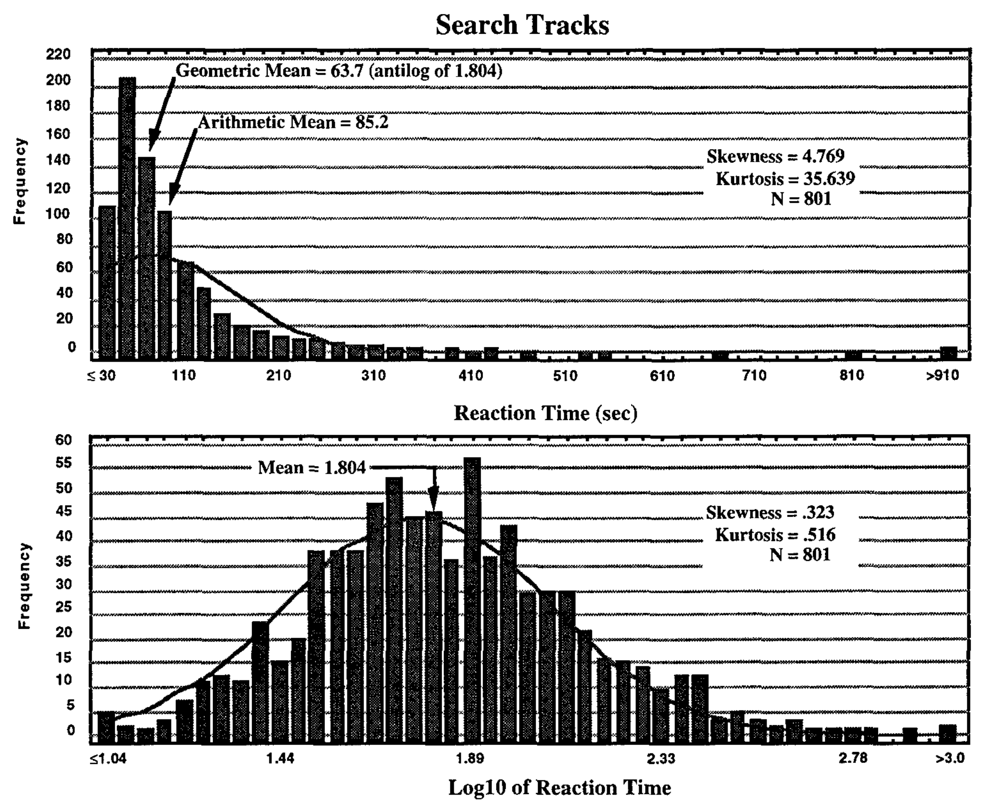


Figure 3: Frequency distributions of detection times to simulated 'Search' tracks. Top figure illustrates the positively skewed raw data; bottom figure illustrates the normalized (log10) transformed data.

A three way ANOVA was performed on the following three factors: track type, shift and hour-into-shift (2 x 2 x 8). Statistically reliable main effects were found for all three factors (track type: $F_{(1,15)} = 497.8$, $P < .0001$; shift: $F_{(1,15)} = 32.73$, $P < .0001$; hour-into-shift: $F_{(7,15)} = 3.55$, $P < .019$) but there were no interactions. Table 1 shows the RT geometric means (with 5-95% confidence intervals) of the main effects for beacon vs. search tracks and the evening vs. midnight shift. RTs were roughly 3 times longer for search tracks (63.7 sec) than beacon (22.9 sec) and the evening shift was 9 seconds faster overall than the midnight shift (48.3 vs. 39.3 sec respectively). Figure 4a illustrates the main effect of RT by hour throughout a shift (collapsed across shift and track type). A marked improvement in performance (≈25 sec) is observed from hour1 to hour2 of a shift. Performance thereafter gradually becomes poorer towards the end of the shift. Although the three way interaction was not significant, Figure 4b suggests that this decline in performance is largely due to slower RTs for search tracks near the end of the midnight shift.

To investigate RTs for the different geographic zones, separate ANOVAs (zone x track type) were performed for the evening and midnight shifts. The evening shift yielded significant main effects for geographic zone ($F_{(4,15)}=5.92$, $P<.0046$) and track type ($F_{(1,15)}=278.75$, $P<.0001$), and an interaction ($F_{(4,15)}=3.78$, $P<.0255$). The midnight shift showed two main effects (zone: $F_{(3,15)}=5.17$, $P<.0119$; track type: $F_{(1,15)}=265.73$, $P<.0001$) and no interaction. Figures 5a & b show the results for the evening and midnight shifts, respectively. During the evening shift search tracks in the North and South East zones are detected much more slowly than in the North East and East. Except for slightly faster RTs in NE1, beacon detection is the same across zones. For the midnight shift, RTs in the North and North East are slower than those in the East, which in turn are slower than those from the South East.

2.3 Discussion

The 30 sec difference in RT between beacon and search tracks is consistent with the findings of the first pilot study. The distinctive symbol (diamond) used for beacon tracks is easily detected on the consoles. Since the radar update interval is 12 seconds the average detection time for beacon tracks is within 2 radar frames (i.e., a trail of 2 'blips'). On the other hand, legitimate search tracks (hyphens) can only be distinguished by their blip-trail trajectories. More time is needed first, to develop a blip-trail history and, second, to detect and differentiate them from background noise (e.g., storms, sea spray). On average, 5 update intervals were needed to detect these tracks (i.e., ≈ 63 sec).

The main effect of shift indicated that on average the evening shift was 9 seconds faster than the midnight shift. It is not clear whether this difference is due to fatigue induced from working the midnight shift or due to the effect of one less console being staffed, compared to the evening shift. The issue of the total number of geographic zones and its overall effect on performance is addressed in Experiment 2.

There were two interesting findings when performance was plotted through time (Figures 4a & b). First, RT was slower during the first hour after a shift change — the effect was most noticeable for search tracks but the trend was also present for beacon data during the first hour of the midnight shift. This result may be due to high levels of social interaction among the operators at the beginning of shifts or it could reflect a latency to re-adopt some unknown 'cognitive set' necessary to efficiently perform the task. Second, there was a progressive increase in RT toward the end of an 8 hour shift.

Performance latencies were also differentially affected by geographic zone. During the evening shift, RTs for radar tracks were longer both in the North and South East zones (see figure 5a). Since the northern zone contained very little air traffic, the slower RTs may have been due to lower operator motivation and arousal. However, the South East zone similarly displayed slower RTs, despite experiencing higher workloads due to evening traffic travelling to

the U.S. from Europe — and thus should have experienced greater arousal and produced better performance. On the other hand, the high amount of air traffic (see Figure 6), may have made detection of search tracks much more difficult.

	Beacon Tracks	*Search Tracks*	**Main Effect for Shift**
Evening Shift	19.5 (17.3 - 21.9) N = 250	58.7 (54.6 - 63.0) N = 436	**39.3 (36.5 - 42.3) N = 686**
Midnight Shift	27.2 (24.7 - 30.0) N = 238	70.3 (65.6 - 75.2) N = 365	**48.3 (45.2 - 51.7) N = 603**
Main Effect for Track Type	**22.9 (21.2 - 24.8) N = 488**	**63.7 (60.6 - 67.0) N = 801**	**Overall** N = 1289

Table 1: Geometric means and 5-95% confidence intervals of RTs for the shift and track type conditions.

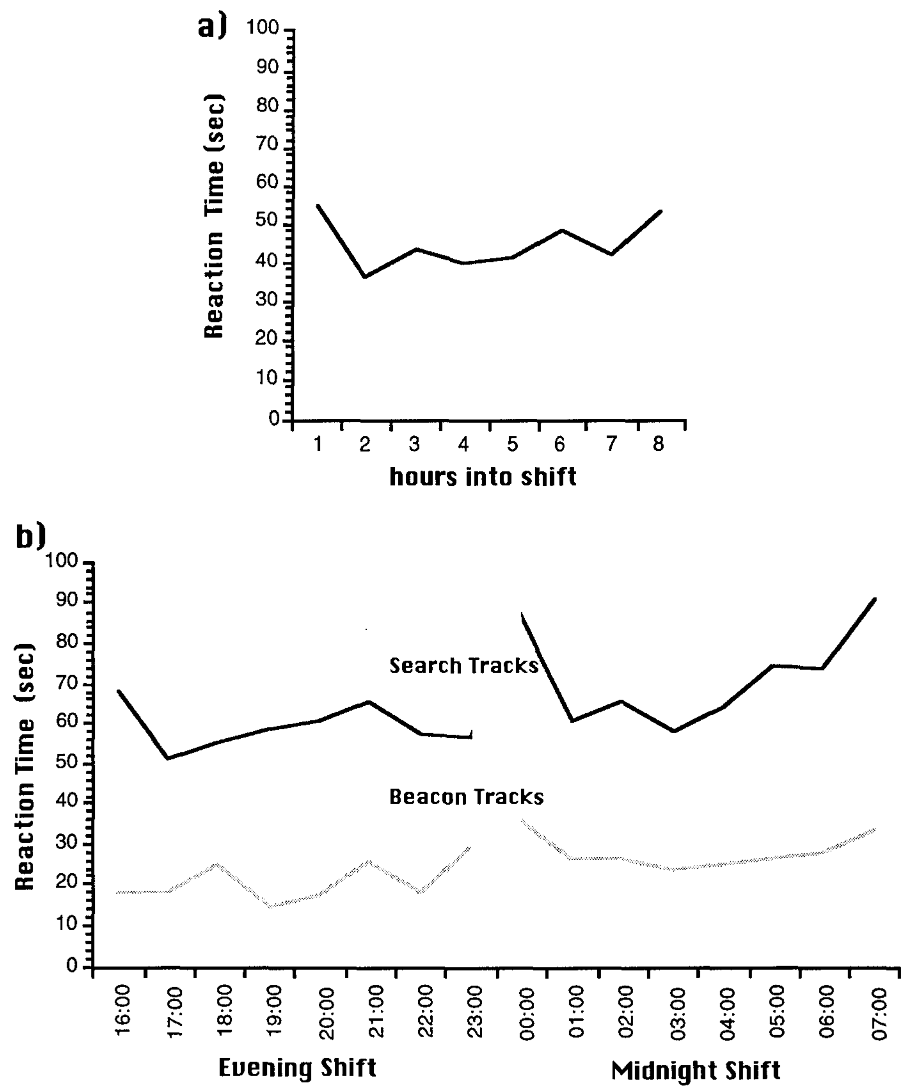


Figure 4: Response times (geometric means) plotted every hour throughout a shift: a) data collapsed across shift and track type; b) data for each shift and track type.

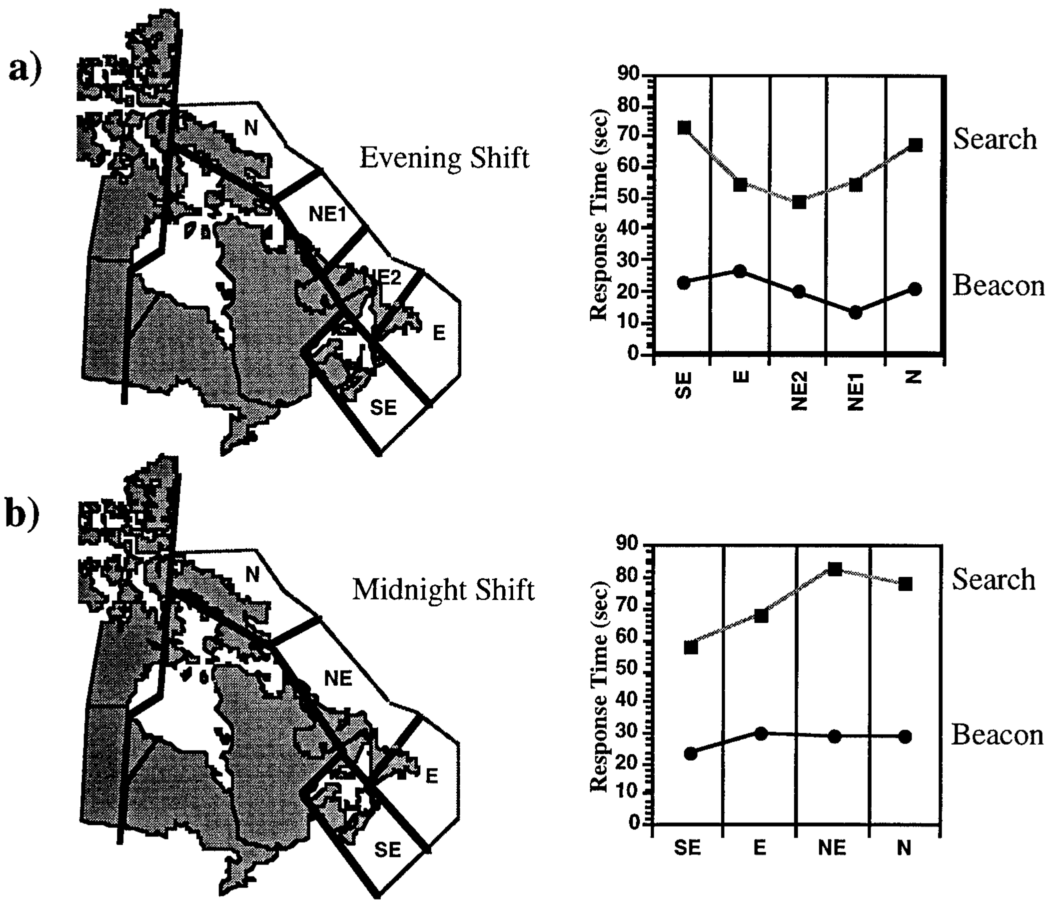


Figure 5: Response times (geometric means) for both track types in each geographic zone: a) evening shift; b) midnight shift.

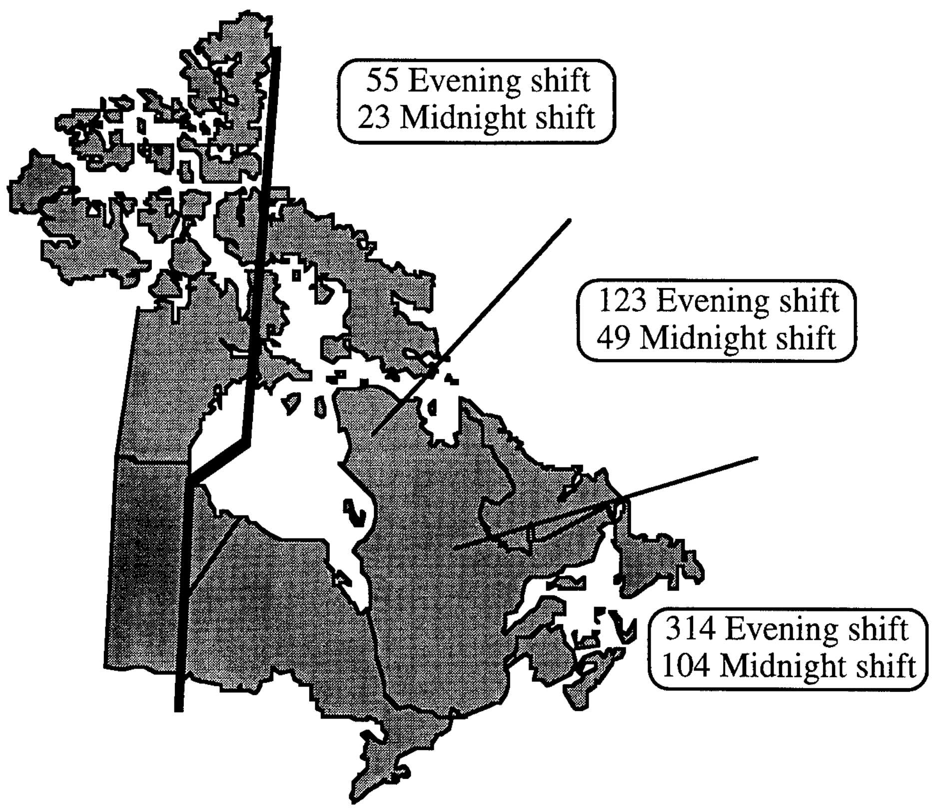


Figure 6: Amount of live air traffic during each shift for different geographic regions.

Figure 6: Amount of live air traffic during each shift for different geographic regions.

During the midnight shift a definite increasing trend was observed for search RTs from the South East to the North (see figure 5b). Slower RTs in the North are likely due to the extremely low amount of air traffic traversing this zone at this time.

In summary, experiment 1 yielded a number of findings: 1) an extended study of a real-world, real-time vigilance task is possible without sacrificing operational efficiency; 2) search tracks are significantly more difficult to detect than beacon tracks, both because they are relatively infrequent events and they have relatively small signal to noise ratios; 3) performance during the first hour of a shift is poorer than during the second hour; 4) detection of search tracks degrades towards the end of a shift — particularly during the midnight shift; and 5) search track performance varies with geographic location of coverage.

3. EXPERIMENT 2

The results from Experiment 1 justified pursuing a more rigorous experimental investigation. Experiment 2 was designed to manipulate two independent variables: coverage area (i.e., number of zones) and time-on-task. The number of geographic zones into which Canada East is divided directly translates into personnel requirements for continuously staffing the consoles. Traditionally, the number of zones usually fluctuated between three and four depending on personnel availability. No data exist demonstrating the degree to which performance is affected by changing area of coverage. Even though the surveillance operator's task is over-learned and extensively practiced, performance could be seriously compromised if the number of geographic zones is reduced; using fewer consoles would require that each console encompass a larger surveillance area. Each aircraft's blip-trail would then subtend a smaller visual angle on the console thus making detection more difficult.

The second independent variable, time-on-task, was included to investigate the vigilance decrement effect observed in Experiment 1, where RTs increased during the latter part of the shift. It was unclear, however, whether performance degraded within individual work periods occurring within any given 8 hour shift. Vigilance research suggests that performance declines should occur after approximately 20 minutes on task [6]. To test this, a condition was added in which the subjects worked for 20 minutes then rested for 20 minutes throughout the duration of a shift, or worked 60 minutes and rested 60 minutes. If the vigilance decrement observed under laboratory conditions can be generalized to real-world tasks then RTs during the 60/60 work/rest condition should be greater than during the 20/20 condition.

3.1 Method

3.1.1 *Subjects*

Sixteen (different) experienced surveillance operators participated in this experiment. Ss were informed as to the general purpose of the study, were assured individual performance would be kept confidential and were promised disclosure of the final results when they became available.

3.1.2 *Procedure*

A 2 x 2 x 2 factorial design was employed to investigate the relationship between coverage, time-on-task and shift. Canada East was divided into either 2 or 4 geographic zones and either 20 min/20 min or 60 min/60 min work/rest cycles were used. Both the evening and midnight shifts received each condition twice, separated by a one month interval. The ordering of the experimental conditions for the first session was reversed for the second session (seeFigure 7).

To ensure that an equal number of data points were collected from each console, 10 simulated tracks per hour were randomly presented in each of the 2 (or 4) geographic zones — unlike in Experiment 1, where a constant 25 tracks per hour were randomly presented across all zones. This resulted in 20 simulated tracks per hour presented during the 2 zone condition and 40 simulated tracks per hour during the 4 zone condition. In total, 3840 simulated tracks were injected during the entire experiment. In contrast to Experiment 1 all simulated tracks were of the same type: search tracks. NORAD officials consider detection of all search tracks their primary task because those not identified may pose a threat to North American security. Also, since RTs to beacon tracks were relatively fast and stable throughout Experiment 1 the decision was made to concentrate on search tracks

	Evening Shift	Midnight Shift
Day 1	2 zones 20/20	2 zones 20/20
Day 2	4 zones 20/20	4 zones 20/20
Day 3	2 zones 60/60	2 zones 60/60
Day 4	4 zones 60/60	4 zones 60/60

Session 1

1 month interval

	Evening Shift	Midnight Shift
Day 1	4 zones 60/60	4 zones 60/60
Day 2	2 zones 60/60	2 zones 60/60
Day 3	4 zones 20/20	4 zones 20/20
Day 4	2 zones 20/20	2 zones 20/20

Session 2

Figure 7: Presentation order of treatment conditions in experiment 2.

3.2 Results

A total of 3322 out of a possible 3840 data points (86.5%) were collected during the experiment — the remainder (518) were lost due to computer problems. Of the collected data, approximately equal numbers were retrieved from both experimental sessions (41.5% for session 1, 45% from session 2). The strategies developed in Experiment 1 for normalizing the data and identifying outliers were applied to these data and resulted in a further 19 data points being eliminated. As in Experiment l, all statistical analyses were performed on the transformed data and group differences are reported as geometric means with 5-95% confidence intervals.

A 2x2x2x2 ANOVA was performed on the following four factors: shift (evening vs. midnight); number of geographic zones (2 vs. 4); time-on-task (20/20 vs. 60/60); and work-session (session 1 vs. session 2).There was a statistically significant main effect for number of zones ($F(1,15) = 81.3$, $P<.0001$). When the surveillance area of Canada East was divided into 4 zones the mean RT was 74.9 sec (73.8 - 76.1 sec). For the 2 zone condition the mean RT was 20 seconds slower — 94.0 sec (91.9 - 96.1 sec). This poorer performance is likely due to the smaller visual angles the targets subtended in the 2 zone condition, making detection more difficult. Parenthetically, this result surprised the surveillance operators who, almost unanimously, told the experimenters (during the study) that two surveillance operators could perform the task as efficiently as four.

There was no main effect for time-on-task, but there was a shift by time-on-task interaction ($F(1,15) = 7.3$, $P<.0164$). The 60 min work, 60 min rest schedule induced ($\approx$10 sec) longer RTs for subjects working the midnight shift than did the 20/20 work/rest schedule (see Figure 8). This suggests that only the midnight shift was susceptible to a vigilance decrement.

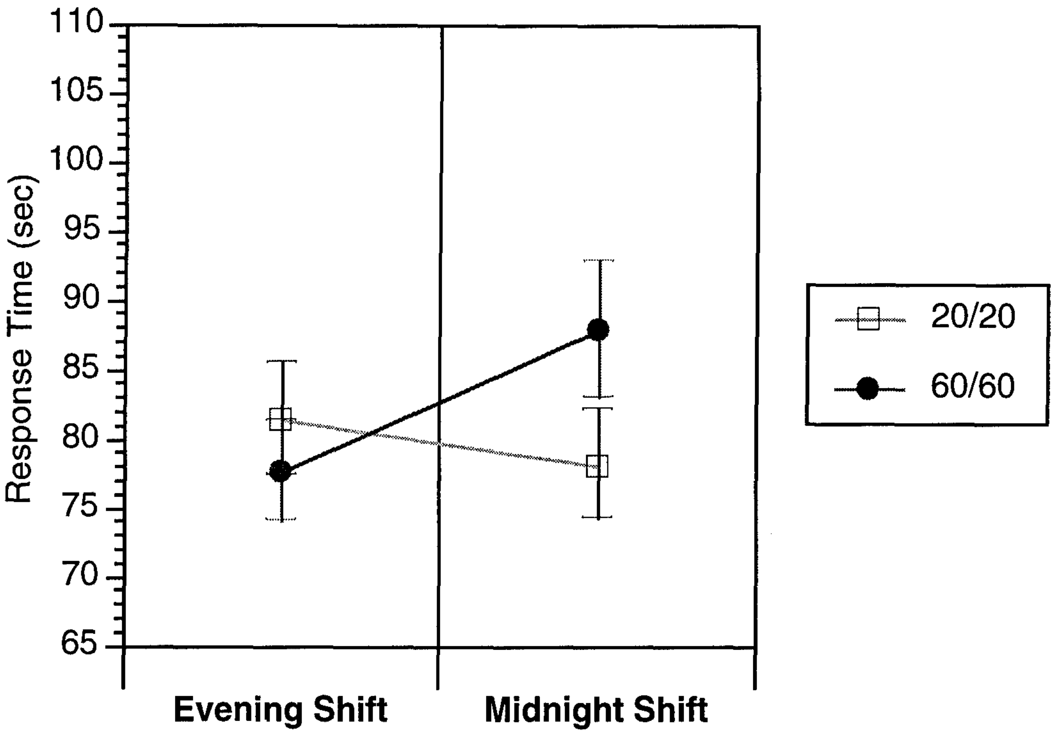


Figure 8: Reponse times for the shift by time-on-task (work/rest schedule) interaction.

In order to investigate the source of this vigilance decrement, RTs were plotted for the evening and midnight shifts for each of the four experimental conditions (see Figure 9). As was seen earlier, the 2 zone condition yielded (overall) longer RTs than the 4 zone condition. However, a statistically significant simple effect was observed only between the 20/20 and 60/60 conditions during the midnight shift for 4 zones. It seems that subjects demonstrated a vigilance decrement only when the following two conditions were satisfied: 1) it was the midnight shift, and 2) Canada East was divided into 4 rather than 2 geographic zones. It is interesting to note that this vigilance decrement was modulated by circadian influences. Figures 10a & b depict hourly RT performances for each work/rest schedule in the 4 zone condition for both the evening and midnight shifts. When subjects are given a 20 min work, 20 min rest schedule hourly performance was relatively stable throughout both shifts. During the 60 min work, 60 min rest schedule, however, a gradual deterioration in performance occurred during the period between 3 and 6 AM of the midnight shift — an effect similar to that observed in Experiment 1.

Also consistent with the first experiment was an improvement in performance after the beginning of a shift. As mentioned earlier, this result could be due to sociological and/or psychological factors. During Experiment 2 we noticed higher levels of non-task related communication among the surveillance operators at the beginning of each shift — suggesting social influences. However, a psychological factor may also have contributed to the effect. Figure 11 depicts changes in RT in 10 minute intervals within the 20/20 and 60/60 work/rest conditions. There was a dramatic (≈ 24 sec) improvement in performance from the first to the second 10 minutes in the 60/60, 2 zone conditions. It seems that, in the more difficult 2 zone condition after 60 minutes of rest, the surveillance operators needed 10 minutes of 're-adaptation' before reaching optimal performance. Although a similar trend exists for the 20/20 condition, it is not statistically significant. Also, these results suggest that there was no within work period vigilance decrement. In both the 2 and 4 zones 60/60 conditions, performance remained stable — i.e., did not degrade — after the first 20 minutes.

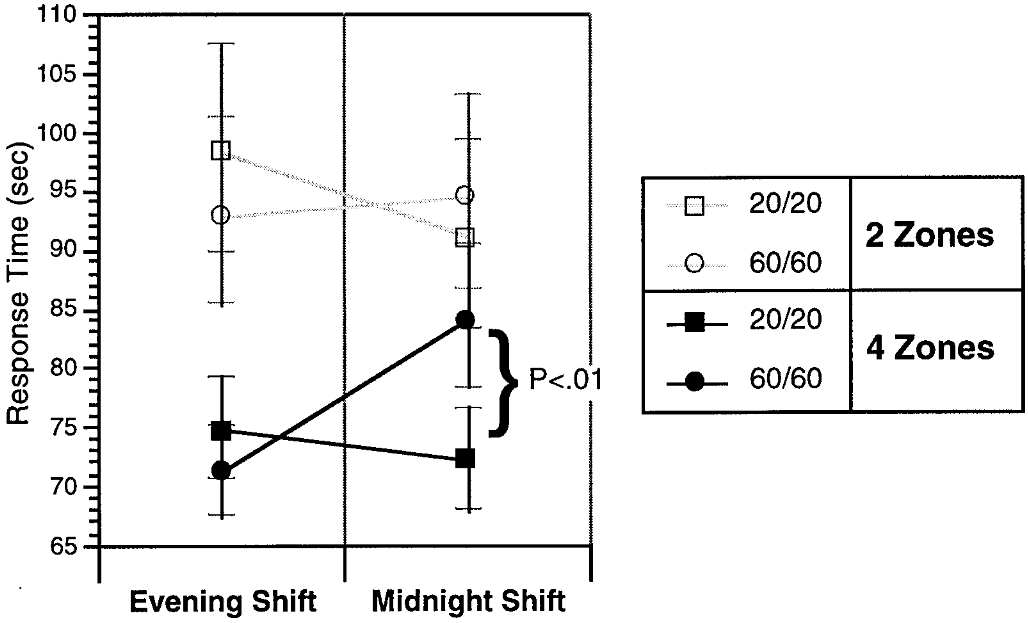


Figure 9: Evening and midnight shift response times for the coverage (# of zones) and time-on-task conditions.

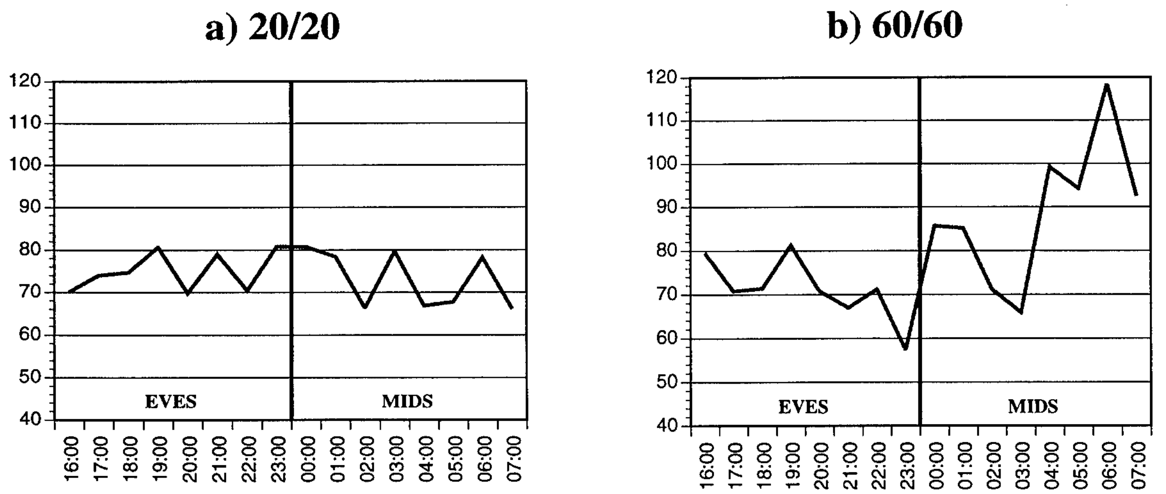


Figure 10: Hourly response times for the evening and midnight shifts in the 4 zones condition: a) 20/20 work/rest schedule; b) 60/60 work/rest schedule.

Why did a vigilance decrement manifest itself for the midnight shift in the 4 zone condition, but not in the more difficult 2 zone condition? To answer this question the data were analysed with respect to geographic zone. Figures 12a & b illustrate RTs by work/rest schedule and shift for the 2 zone condition. There were no statistically significant differences in RT between zones for either the 20/20 or 60/60 work/rest (time-on-task) conditions. This is despite the fact that a large difference exists between the proportion of air traffic traversing the East (E) vs. the North (N) zone. These results are contrasted with those presented in Figures 13a & b in which there were statistically significant shift by time-on-task (F(1,15) = 11.0, P<.0047) and shift by zones interactions (F(3,15) = 11.2, P<.0004). Figure 13a shows that operators working the midnight shift in the 20/20 work/rest condition performed more poorly from the South East (SE) to the northern zones, whereas performance across regions for the evening shift remained stable. The vigilance decrement during the midnight

shift is even more pronounced in the 60/60 work/rest condition, particularly for the East (E) and North East regions (Figure 13b). These results suggest that operators working northern regions (i.e., low air traffic) during the midnight shift were more susceptible to vigilance decrements, particularly during the tiring 60/60 work/rest condition. Although there is certainly a circadian influence contributing to these results, this explanation does not account for the unchanging performance observed in the 2 zone condition.

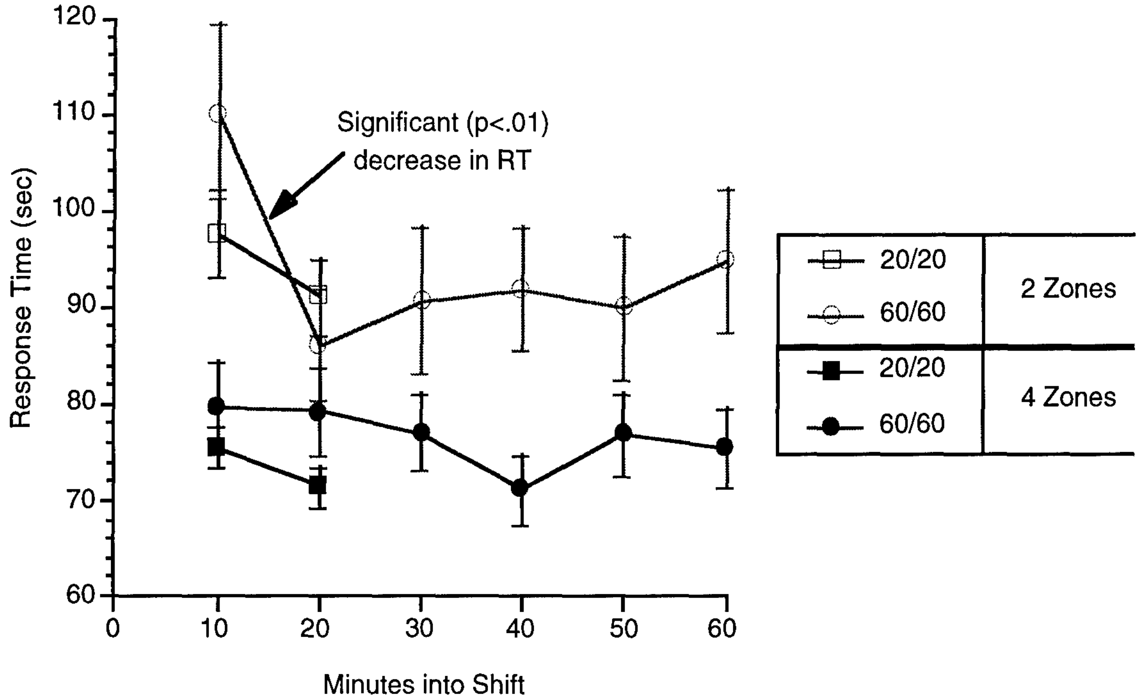


Figure 11: Response times in 10 min intervals from the begining of each work period.

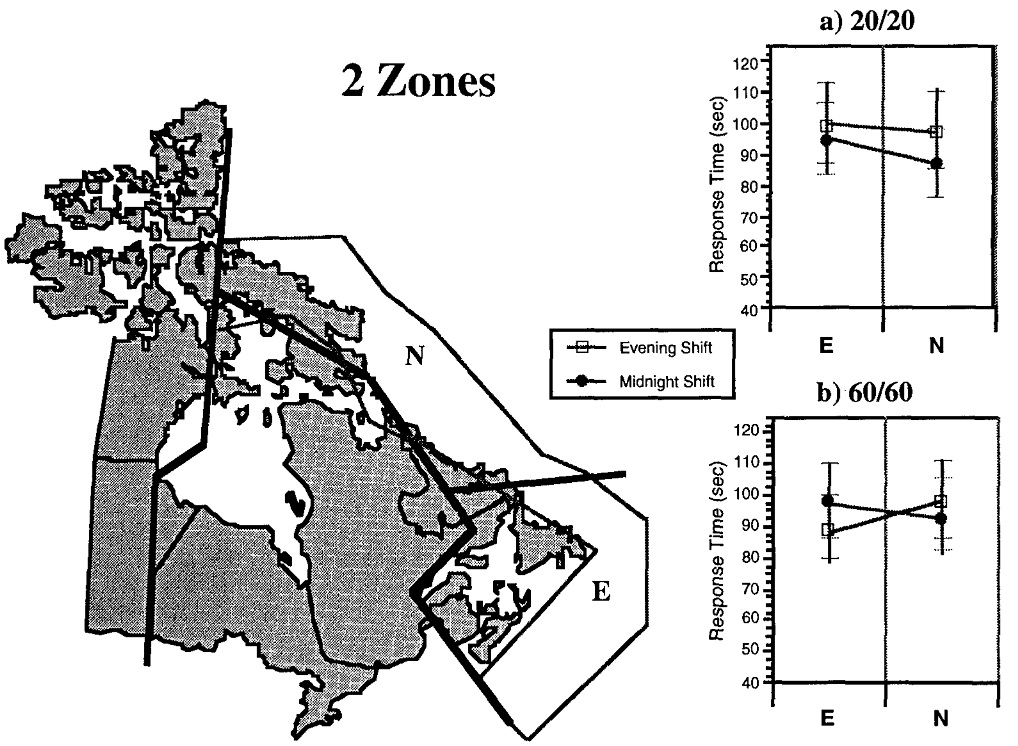


Figure 12: Response times for time-on-task and shift for each geographic area in the 2 zones condition.

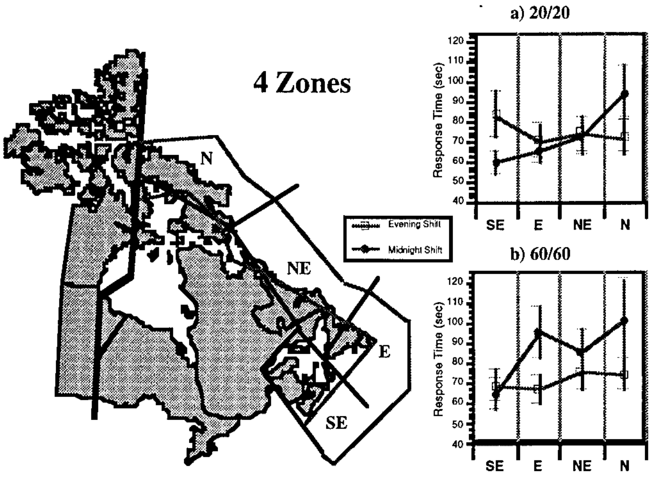


Figure 13: Response times for time-on-task and shift for each geographic area in the 4 zones condition.

It is unclear why the more difficult 2 zone condition did not show a similar decline in performance from the East to the North zones. We expect that motivation may have played a key role. During the experiment (4 zone condition) we noticed that operators in the midnight shift, surveying the northern zones, attended to their consoles less and communicated with their neighbors more. This may have been an unconscious strategy among the operators to keep themselves awake while monitoring low (i.e., boring) traffic areas. In contrast, the northern most operator in the 2 zone condition was probably discouraged to engage in idle discussion because his/her neighbor was busy with the more difficult East zone; hence, perhaps reinforcing better performance in the northern operator's area. Another possible motivational influence was the physical proximity to the surveillance supervisor in the 2 zone condition. In NORAD, the role of the surveillance supervisor (who did not take active part in the experiment) is to ensure the efficient operation of the surveillance team. Figures 14a & b illustrate the placement of the consoles with respect to the supervisor's console and show that, unlike the northern most consoles in the 4 zone condition, consoles in the 2 zone condition were situated near the supervisor. It is possible that this proximity to the supervisor could have provided extra motivation — motivation necessary to overcome boredom and fatigue from surveying the north during early morning hours.

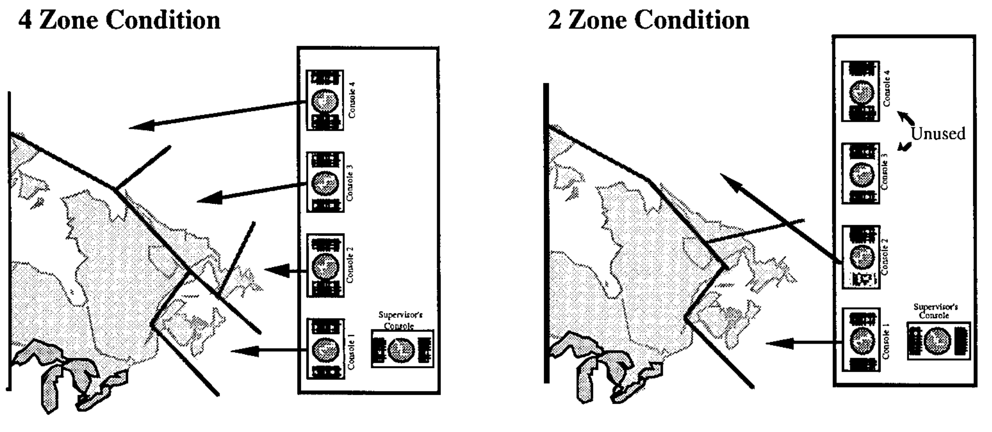
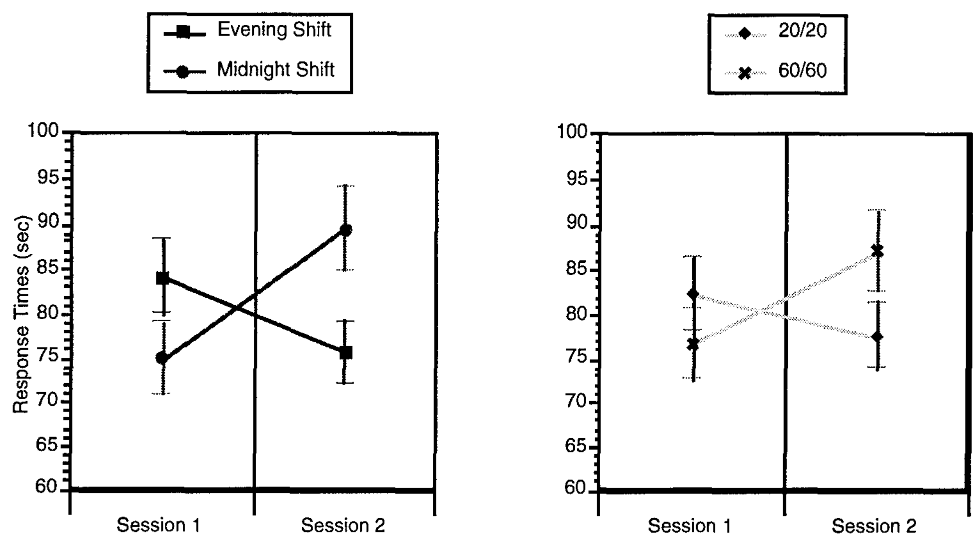


Figure 14: Physical layout of consoles for the 2 and 4 zones conditions.

There was no main effect for work-session, indicating there was (overall) no difference between the first and second testing sessions. However, there were 2 two-way interactions: work-session by shift (F(1,15) = 27.3, P<.0001) and work-session by time-on-task (F(1,15) = 18.1, P<.0007). Figure 15a shows that between the first and second testing periods RT increased during the midnight shift but decreased during the evening shift. This decrease in response times for the evening shift is likely due to differential radar clutter. During the first two days of session 1 there was considerable radar clutter in the South and South-East zones. Relatively little clutter was present for all geographic zones during all of session 2. Although the midnight shift similarly experienced clutter during the first two days of session 1, RTs increased rather than decreased in session 2. Ironically, a simpler detection task for the midnight shift may have had a de-arousal effect on the subjects making them more susceptible to circadian influences. The results in Figure 15b, which display the work-session by time-on-task interaction, support this interpretation. From session 1 to session 2 RT increased for the 60/60 work/rest condition but slightly decreased for the 20/20 condition.

In summary, Experiment 2 yielded the following findings: 1) detection times took approximately 20 seconds longer when Canada East was divided into 2 rather than 4 geographic zones; 2) the 60/60 work/rest condition produced an overall vigilance decrement only for subjects working the midnight shift in the 4 zone condition; 3) in the 4 zone condition for the midnight shift, operators surveying northern zones demonstrated greater vigilance deficiencies than those surveying southern zones; 4) these subjects were also susceptible to circadian influences; and 5) a (≈ 10 min) period of readjustment was needed for subjects to reacquaint themselves with the detection task in the 2 zone, 60/60 condition.



(a) (b)

Figure 15: Experimental session by shift (a) for time-on-task (b) and interactions.

3.3 Discussion

The results from this study are consistent with Parasuraman's [16] assertion that, "...vigilance failures in complex monitoring do occur and may result either from a vigilance decrement or from a low overall level of vigilance" (p. 700). Contrary to other researchers [e.g., 1, 13] Parasuraman [15, 16] has maintained that the vigilance decrement is a robust effect and can be found in real world situations. Although our results suggest that, in the NORAD environment, vigilance failures do occur, the lack of an overall vigilance decrement (i.e., main effect for time-on-task) in Experiment 2 is also consistent with criticisms that the effect generalizes poorly from the laboratory to the real world [1, 11, 12, 13]. The 60/60 vs. 20/20 work/rest condition produced longer response times

only under conditions where the geographic region was divided into 4 zones and the surveillance operators worked midnight shifts. As in Experiment 1 the gradual decline in vigilance during early morning hours is consistent with chronopsychological studies showing that cognitive performance is sensitive to circadian influences e.g., [3, 8, 9].

Among the many factors posited in the literature to explain small or nonexistent vigilance decrements in real world settings are target probability, stimulus rate, stimulus complexity, task type, skill level and motivation. It has been suggested that a stimulus rate of at least 24 [14] or 20 [23] events per minute is needed to observe a vigilance decrement. The stimulus rate (i.e., target + non-target) in our study could not be precisely calculated because the number of non-targets (i.e., spurious radar tracks) varied dynamically with the physical environment. Nevertheless, we estimate that, given the relatively large amount of radar 'clutter' present on the operators' consoles during the experiments, a stimulus rate at least as great as 24 events/min was occurring. Even though the number of simulated tracks per consoles was kept constant, the overall target rate (i.e., simulated + live tracks) varied from ≈ .2 event/min in relatively sparse northern zones to ≈ 1 event/min in high traffic areas. There are two reasons why it is unlikely that this difference in target probability is responsible for the poorer performance observed among operators working the northern zones. First, there was no similar effect for the 2 zone condition; and second, the 4 zone/evening shift condition also showed no effect despite comparable target probability distributions among the respective geographic zones.

Parasuraman [14] distinguished between two types of vigilance tasks: (1) those that involve successive-discrimination where "...the target and nontarget features are not present at the same time" (p. 924) and thus induces short term memory loads; and (2) simultaneous-discrimination tasks where targets are at all times fully discriminable from nontargets. In Experiment 1, the detection of beacon tracks, with their unique symbology, could be classified as a simultaneous-discrimination task. The detection of search tracks, on the other hand, involves successive-discrimination because targets can be distinguished from nontargets only by comparing 'blip' trail lengths. From a survey of the literature Parasuraman [14] established that reliable vigilance decrements are observed only for successive-discrimination tasks with high event rates. Our results are consistent with this conclusion. Response times for detecting beacon tracks in Experiment 1 did not indicate vigilance failures, whereas response times for search tracks did. This factor alone, however, does not explain why an overall vigilance decrement — main effect for time-on-task — failed to occur in Experiment 2 where all stimuli were of the successive-discrimination type.

NORAD personnel are highly trained and skilled surveillance operators. It is possible that this training and experience could have offset any vigilance decrement expected from a 60/60 work/rest schedule. Parasuraman and Giambra [15] have shown that practice can reduce or even eliminate vigilance decrements. In their study, three groups of subjects (young = 19-27 yrs, middle aged = 40-55 yrs. and old = 70-80) were allowed 20 practice sessions on a 30 minute vigilance task. During the first two sessions the percentage hit rate decreased for all subjects from the first to the third 10 minutes of the task — i.e., a noticeable vigilance decrement. By the 19th and 20th practice sessions, all three age groups showed marked improvements in resisting vigilance decrements with the youngest group totally eliminating it. The subjects in our study were all young and well trained military personnel. This combination of youth and extensive practice could account for the lack of an overall decrement effect.

A vigilance decrement occurred only for operators working the midnight shift when Canada East was divided into 4 surveillance zones. It is known that vigilance decrements are sensitive to diurnal influences [5, 18], but it is unclear why the effect was not exhibited for the 2 zone condition. We posit that motivation played an important role to assuage circadian induced vigilance decrements. Warm, Dember, Lanzetta, Bowers, and Lysaght [21] demonstrated that by increasing the level of complexity of a task, vigilance decrements can be reversed. They attributed this finding to greater intrinsic motivation elicited by tasks of greater complexity. The 2 zone condition elicited response times 20 sec longer (overall) than those observed during the

4 zone condition. This suggests that the surveillance task was more difficult to perform and, as such, could have provided greater intrinsic motivation to maintain efficiency during the midnight shift.

Intrinsic motivation is motivation elicited by an inherent interest in the task. Extrinsic motivation — i.e., pressure to perform imposed by an outside source — may also have played a role in the results. Horne and Pettitt [10] found that subjects performing an auditory vigilance task can resist circadian induced vigilance decrements if sufficient monetary incentives are given. The ameliorating effects of this extrinsic motivation did not continue, however, past the third night of sleep loss in their study. In the NORAD environment, the surveillance supervisor is responsible for ensuring that all radar tracks entering Canadian air space are quickly detected by the team of surveillance operators. Consequently, this person can be a source of considerable influence and motivation to the subjects. Simple physical proximity to the supervisor may motivate operators to maintain performance during the early morning hours. Both surveillance operators were situated near the supervisor in the 2 zone condition. In the 4 zone condition, operators of northern zones were situated further away. From informal observations during the experiment, we noticed that northern operators were allowed greater latitude (by the supervisor) to partake in non-task related behaviour. As a result, these operators may have experienced less extrinsic motivation to efficiently perform their task. We suggest therefore that, among these highly trained individuals, a vigilance decrement is manifested only when the following two conditions are met: 1) low central nervous system arousal due to circadian influences (i.e., midnight shift), and 2) reduced intrinsic and/or extrinsic motivation to properly perform the task (i.e., less demanding task and/or less supervision).

Our finding that performance improves from the first to the second 10 minutes on task, after a 60 minute break for the 2 zone condition, is intriguing. For this real world task, it appears that a break lasting 60 minutes is sufficient to require a period of cognitive/perceptual readjustment after which performance improves (a vigilance increment effect?). Recall that the subjects rotated among the consoles in both the 20/20 and 60/60 work/rest conditions, thus encountering different radar information each work period. The effect is therefore not due to the radar picture simply having had more time to change during the 60 vs. 20 min rest period. It appears that highly skilled surveillance operators need approximately 10 minutes of 'practice', after a 60 min break, to reach asymptotic levels of performance in the more complex and less familiar 2 zone condition. This interpretation is consistent with Pellegrino, Doane, Fischer and Alderton's [17] study in which they found that improvements in performance to a perceptual comparison task was a function of both the amount of practice and the context in which responses were elicited. It appears that in the more familiar and less difficult 4 zone condition, a period of 'practice' is not necessary to regain optimal performance after a 60 min break.

In conclusion, our results suggest that a vigilance decrement effect can occur in a real world detection task. The effect, however, is 1) not nearly as strong as those reported in laboratory studies and 2) is limited largely to the midnight shift. Also, with the judicious use of intrinsic and/or extrinsic motivation, it may be possible to eliminate this vigilance decrement effect altogether.

4 ACKNOWLEDGEMENT

The authors would like to thank the Commander and staff of the 22 Wing at Canadian Forces Base North Bay for their assistance with these studies. In particular we would like to thank the crew of 21 Aerospace Warning and Control Squadron, who were subjects in the experiments, as well as the 'sim' input team for their efforts. A working group, headed by LCol J.A. Nelson, deserves thanks for implementing the experiment. Among this team, two people deserve special mention: Warrant Officer W.E. Horsman who organized the sim inputs and Captain M.Y. Dubois who undertook the data reduction.

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EFFECTS OF STRESS ON THE IMMUNOCELLULAR SYSTEM IN MILITARY PILOTS

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INTRODUCTION

Since 1964 when GEORGE F.SOLOMON coined the term "Psycoimmunology" and published "Emotions,immunity and disease:a speculative theoretical integration"(1),and later ADER and COHEN(1975),with their investigations,created a theoretical framework of the new approach to the investigations,a lot of papers have been published dealing with the relationship between the CNS,the neuroendocrine system and the immunological system(20,23).

In studies on the CNS and the Immune System,both with a great capacity to receive and respond to any kind of stimulation -exterior as well as interior- it has only recently been considered that both are not completely autonomous,but that the interrelationship is more and more complex as investigations reveal new facts. According to ADER(1,23),all homeostatic defense organic systems are subject in a greater or lesser degree to the influence of environmemtal circumstances and psycological factors,whose integration evokes an adaptative response which,at the last moment,is regulated by the brain and whose consequences on health are not very well known at present.

It was precisely psycoimmunology which tried to relate the advances in this unexplored field of the relatioship between the CNS,the Immune System and the Neuroendocrine System.The abundant information available tells us,not only of the neuroendocrine communications(hormones),but also of the neuroanatomical kind (vegetative nervous system fibers) and neurochemical(neuropeptides and cytoquines) and,that these communications are didirectional, establishing a regulating circuit for the biofeedback and bioforward mechanisms even though we do not know yet how these molecular signals interact between each other(Table X).

One of the aspects which has been investigated in depth is the relationship between stress and immunity.Although the influence of psycological factors on the susceptibility and course of many diseases has been long known (DUBOS,1965;SHUKULA,SOLOMON,DOSHI, 1979)it has not been until recently,as we have mentioned,that interest has directed towards how psycological factors influence the immunological systems of the organism in certain diseases like cancer,infections and autoimmune

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diseases (COE and LEVINE,1984),and the actions of stress and diverse neurological and psychiatric disorders on immunity.

It is known by all that high psycosocial stress situations (divorce,grief,bereveament,..) are associated with a deteroration of the Immune System and therefore more susceptibility for the person to fall ill(11,12).The published facts,both in animal investigation as well as human,speak in favour that stress can alter the basic processes in healthy subjects under diverse psycosocial conditions.

However,the topic of stress is complex and problematic,both for its delimitation concept as well as the methodology of its study(9).In this paper we are going to consider stress,according to the definition given by LAZARUS and FOLKMAN,as "a particular relationship between a person and his surrondings which is considered by him to be a burdensome or which exceeds his resources,and which risks his well-being or health",and we attribute a cognitive model of the evaluation which makes the subject of the stressful events we will modulate according to resolute characteristics of his personality, perceived social support and suitable coping strategies of the same(Table XI).

Due to the lack of scientific literature which considers the inunological repercussions of stress,which what was said beforehand, and more so in the military pilot population(3,18), this paper has been designed evaluating the scoring of four scales or questionaires which reflect the balance of the vital stressful events,the perception of social support of each individual, the anxiety trait and the construc known as "Locus of Control" to verify what influence can have on the immunocelular state of this type of population,and so on the funcional state of the immune system.

MATERIAL AND METHODS

The project and development of this paper took place in the Aviation and Space Medicine Institute(C.I.M.A.)in Madrid,in colaboration with the Spanish Air Force Hospital,choosing from the population of military pilots of high performance aircraft,who came to the before mentioned Center,to renew their flight fitness for said aircraft.

The sample was taken at random,choosing the first 23 pilots who,during period of this study,came in for a medical check-up.A previous condition was not to present any medical disease,not medical history or analytical antecedents of interest,precise extremes depending on the results of check-ups carried out in other departments of this Center and of the interview held with the subjects,the other condition was that the subjects were actually flying this kind of aircraft.

Once the pilot was chosen, and after the compulsory information of the study taken and the subjects asked for their consent, the different questionnaires were handed out,and a brief explanation of the instructions given as to

how those should be answered.The questionnaires used were as follows:

-Personal detail sheet in which information relating to age,sex, marital status,number of children type of aircraft,years of service, flying time,military rank,and Service.

-Stressful Life Events Questionnaire,by JJ.CASTILLON(7):a questionnaire designed from the proposal by RAHE-HOLMES,and adapted to the Spanish populations by the authors of the same and which registers and quantifies the vital changes in the last twelve months.

- Anxiety Trait-State Inventory (STAI) by C.D.SPIELBREGER:only applied to the corresponding subscale of the anxiety feature(14).

- Self-Applied questionnaire for the evaluation of stress social support from the Department of Mental Health of California (1981):this was only applied to the subscale of social support for the evaluation of social support of the subject according to the level of emotional and social relationships.

- Valuation scale of the Locus of Control by ROTTER,Spanish version (4,15),by POLAINO and VILLAMISAR (1985).

The determination of the immunocellular parameters was obtained after a blood sample of each pilot was taken,by means of the flow cytometer from the BECTON DICKINSON Company,and the use of monoclonal antibodies(16)mixed with fluoresceine isotyocyanate (FITC) and ficoeritrine(PE),for the quantization of.the following mature lymphocyte subpopulations:

- Lymphocyte T: CD3+ (FITC)
- Lymphocyte B: CD19+ (PE)
- Lymphocyte T helpers: CD4+ (FITC)
- Lymphocyte T suppressors/cytotoxics: CD8+ (PE)
- Lymphocyte T activated: CD3+ HLA-DR+
- Lymphocyte T cytotoxics: CD3+ CD16+ CD56+
- NK cells ("Natural Killer"):CD3- CD16+ CD56+

Finally,for the processing of the information and the statistical analysis the package SPSS (Statistical Package for Social Sciences)was used.

RESULTS

The study was made up of 23 military pilots members of the Air Force who fly high performance aircraft(Table II),all were male,6 of whom were single(26%) and 17 were married (74%) with an average of 1 child(SD=1).

As we can see from the Table I,the average age was 32.6 years (SD=6.4), with an average flying time of 1989.1(SD=1046.3) and 12 years in the Service(SD=7.1).

The results of the study of stressful factors and psycological constructs which modified its impact on the organism can be seen

in Table III.

The quantization of stressful factors,according to the questionnaire by JJ CASTILLON, registered an average of 2.92 points(SD=2.06),with 78.2% of pilots having less than 4 points(Table III).

The social support received by them was valued as a means of obtaining a score between 15 and 29(78.5% of the study group,18 subjects),in 2 subjects(8.6%)it was low,while in 3(12.9%) it was high, being the average score in general was 24.35 points(SD=5.89).

The anxiety trait reflected an average 3.43 points(SD=2.13) on the decil scoring,with 78.2% of pilots being under 5 decil(Table III).

The Locus of Control which showed us where to locate the subject's control facing actual experiences -supplied by ROTTER'S questionnaire- reveled an average of 9.82(SD=3.67),placing itself within the internal Locus of Control on actual experiences, which are associated to their own conduct.

Finally,from a descriptive point of view,the statistical facts of the lymphocyte subpopulations obtained by means of the flow cytometer,is shown in the Table IV.

The statistical analysis of the aforementioned immuneocellular parameters followed a normal distribution according to the Kolmogorov -Smirnoff Test; considering the average and the standard deviation and comparing the values considered normal by the laboratory on subjects of the same race and age(17),showed a significant decrease($p< 0.001$) of lymphocyte B(CD19+),activated T lymphocytes(CD3+ HLA/DR+) and the ratio CD4/CD8,as well as a decrease($p<0.01$) of lymphocyte T (CD3+),with an increase in the proportion of CD8+ cells and NK cells ($p<0.001$)as we can see in the Table VI.

When the averages and standars deviations were compared by means of a bilateral contrast,and before dividing the model in two, according to the 50 percentage value(median)in each one of the relative values to age,flying time and scoring in the four questionnaires used,no significant statistical difference was observed,except the value in the percentages of CD4+ cells in those pilots of the study with more vital stressful events in which these cell populations were increased(Table VII).

The calculation of the correlation coefficient between the results of said questionnaires did not show any significant levels with the immunocellular parameters.There was a correlation between the STAI and ROTTER'S questionnaire values giving a coefficient of 0.45 ($p<0.05$).

The distribution of active T lymphocyte and the scoring of ROTTER'S test were adjusted to a rational equation curve with a correlation coefficient of 0.81,without any significant statistical differences between the remaining instruments and the percentage of immunocompetent cells.

Finally,the analysis of lineal and polynomic regression reflected the values shown in Table VIII,where

we can see lineal adjustments,with an acceptable error probability between the values of ROTTER'S questionnaire and activated T lymphocyte and a polinomic regression of the second grade between the same test and the percentage of CD+4 cells ($p<0.05$).

DISCUSSION

Although the number chosen could not have been higher,due to the characteristics of the study,it was more than suficient to represent age,sex,marital status,and Service they belonged to,the aircraft piloted,flying time and years of service in relation to the military pilot population who came to this Center.The dispersal of these variables was greater in the number of children(CV=104.4%) and more moderate in years of service(CV=59%),being more acceptable in computed flying time(CV=52.6%),and good in the age of each pilot (CV=19.6%).

Within the framework of the cognitive model of stress(Table XI),the election of the instruments used tried to cover the different links in the chain of said model,choosing those which were available and adapted or valid for the spanish population. In the case of J.J.CASTILLON's stressful life events questionnaire,the facts were very disperse (CV=70.5%) and the average obtained showed an intense medium-low in the number and seriousness of actual experiences in the last 12 months.

With less disperse facts(CV =61.9%),the evaluation of the anxiety trait supplied by the STAI,showed a low level of anxiety as a component of their personality(average=3.43;SD=2.13) expressed in deciles,which indicates a greater control of stressful environments, and a lesser corporal repercussion expressed as an anxiety reagent(8).

The evaluation of received social support presented an acceptable dispersal rate(CV=24.2%),revealing 18 pilots (78.5%),receiving support considered as medium (between 15-29 points)and high (more than 30 points) in three cases(12.9%) with only 2 pilots(8.6%) who were considered low (between 0-15 points),this meant that the majority (91.4%) were estimated as receiving a medium-high level of this construc which in other investigative papers (10,22) has been evalueated as an influence factor in the modulation of stress.

Likewise,the Locus of Control evaluated with ROTTER'S questionnaire, and applied in other investigative studies on pilot population(4),in which it was considered internal,in our study it reflected figures with a not very high dispersal factor(CV=37.4%) and which permitted us to also estimate as internal,and with it controling the exterior experiences under control of one-self,and less dependent on others, which united with what was mentioned beforehand,allows us to afirm the existence of low level psycosocial stress and some good defense mechanisms of facing and modulating stressful factors which makes it easier to face their own stress in an aeronautics performance,which brings with it a better output in aeronautical

operations.

But the immuneocellular state of the selected sample obtained by the flow cytometer and expressed as a lymphocyte subpopulation percentage (Table IV) showed significant differences in almost all parameters with respect to values considered normal (Table VI).The analysis was carried out by means of a comparison of averages in each parameter with respect to the normal values supplied by the manufacturer of flow cytometer(17).Here we can see the decrease in the percentage of total T lymphocyte(present in 73+6.5% of periphery lymphocytes) and B lymphocyte(present in 14 + 4.2% of periphery lymphocytes) with a percentage increase of cytotoxic/suppressor T cells (which comprises of 33+7.4% of periphery lymphocytes,also including some NK cells and other subpopulations which produce suppression of B cells),as well as a decrease in the CD4/CD8 ratio and activated T lymphocyte with an increase in NK cells.These results tell us of the affectation in the pilots' Immune System with respect to the referencial values(decrease of lymphocytes B and T and the CD4/CD8 ratio) which at the moment we cannot give a clear clinical meaning.The immunological alteration detected cannot be rendered,until now, in a greater susceptibility to infection,tumors or autoimmune diseases in the study group,but whose clinical relevence in other studies (3) related the increase of CD8+ cells(lymphocyte suppressors being among them) and the decrease in CD4/CD8 ratio to numerous immune disorders (from autoimmune diseases to viral infections and cancer),we must remember that although a relative immuneodeficiency state does not necessarily have to cause a clinical disease if there are no other associated pathological events,this is why it is advisable to run additional studies to establish a clinical relevance of these results because of their implication in the criteria for choosing pilots(5).

Therefore in our study, this capacity to face stress was not reflected in the repercussions at physiological levels,as we found unusually low values in the immuneological parameters studied.

Nevertheless, the interpretation of the results should be made with caution,as the average values and 95% of each immuneological values have been compared to each parameter;it is advisable to observe the pattern of the total immunological data obtained, instead of the evaluation of each subpopulation isolated(5). Moreover,other factors have not been considered,like smoking (increases cell population but reduces its funcional capacity), alcohol consumption (reduces cell population but increases its funcional capacity)(5),...although race and age was considered.

The comparison of the percentage distribution of CD4+ cells,before dividing the study group in to two according to the average value of scoring on J.J.CASTILLON's questionnaire was the only parameter with any significance (Table VII),it has no value in our study without considering the rest of the immune populations which reflect the same alteration pattern which was observed in the sample.

Finally,even though the

correlation did not establish any significant differences between the values of the questionnaires and the immune state,the scoring of said questionnaires showed significant correlations according to the lineal regression and polynomic models (Table VIII) in the CD4+,CD3+HLA-DR+,NK cells and CD4+CD3+HLA-DR+cells,respectively. This could indicate the existence of an acceptable relation ($p<0.05$) between the scoring on the social support, J.J.CASTILLON and ROTTER's questionnaires and the beforementioned subpopulations,and other papers which could define better and with a greater lineal adjustment.

As we can see the modification in the distribution of the periphery lymphocyte subpopulation in the study,makes us think of an alteration of immune competence, which following our model,shows us some pilots with a low level of psycosocial stress and with adequate resources to face stress,according to the instruments used,but which do not significantly influence the pattern or the outline of abnormal immune parameters,but it does influence in some isolated variable immune competences -enough for consideration- as we have seen beforehand,not knowing the consequences of maintaining stress over a long period of time or if the more stressful group would evolve worse or present a pathologic framework with respect to the non-stressful group, so it has to be completed with other additional investigations which use more subjects in the sample population,the establishing of control groups,comparison of other pilot groups and the determining of funcional parameters of the Immune System,like the production and response of interleukines and the hormone levels of stress and admit under the model which we assumed that the evaluation of aeronautic stress,not analyized but seen(Table IX) could potenciate and promote the immuneodeficiency values found,and which leads to the detection of stress levels which deteriorate the immune functions,using appropriate questionnaires.

To finish,not forgetting another dimension which has revealed a great importance in modulating the impact of stress like the personality of the subject.This variable, difficult to measure,should also be studied in any future studies on stress.

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TABLE I Statistics values obtained from the sample

	m	sd	Sm	CV
Age	32.6	6.4	1.34	19.6
Number of children	1	1	0.21	104.4
Years of Service	12	7.1	1.48	59
Flight hours	1989.1	1046.3	218.1	52.6

m = mean; sd =standar desviation; standar error; CV=constant of variation
$p<0.05$

TABLE II Statistics values obtained from the sample

	n	%		n	%
Sex			Jet		
Man	23	100	F-18 Hornet	8	34.7
Woman	0	0	F-1 Mirage	8	34.7
			F-5B Northrop	4	17.3
Marital Status			RF-4C Phantom	3	13.3
Single	6	26			
Married	17	74	Rank		
Army			Lieutenant	5	21.7
			Captain	11	47.8
Air Force	23	100	Major	4	17.4
Others	0	0	Lieut.Colonel	3	13.1

n =number; %= percentage; $p<0.05$

TABLE III Values from the psychological tests

	m	sd	Sm	CV
SLEC	2.92	2.06	0.43	70.5
Social Support	24.35	5.89	1.23	24.2
STAI	3.43	2.13	0.44	61.9
Locus of Control	9.82	3.67	0.76	37.4

m= mean; sd= standard desviation; sm= standar error;CV= constant of variation
SLEC= Stressful Life Events Cuestionaire;$p<0.05$

TABLE IV Lymphocyte Parameters as Percentages of Total

	m	sd	Sm	CV
CD19 Cells	9.52	3.12	0.65	32.7
CD3 Cells	68.78	5.97	1.25	8.6
CD4 Cells	43.26	7.48	1.56	17.2
CD8 Cells	41.08	9.08	1.89	22.1
CD4/CD8 Ratio	1.04	0.33	0.069	31.4
CD3 HLA-DR Cells	8.13	3.74	0.78	46
CD3 CD16-56	6.08	4.73	0.98	77.6
NK Cells	21.91	7.99	1.67	36.5

m= mean; sd=standart desviation; sm= standart error; CV=constant of variation
$p<0.05$

TABLE V Lymphocyte Parameters expressed as Absolute Counts

	m	sd	Sm	CV
CD19 Cells	210	83.2	17.3	39.6
CD3 Cells	1513.4	386.6	80.6	25.5
CD4 Cells	940	238.9	49.8	25.4
CD8 Cells	918.2	347.3	72.4	37.8
CD4/CD8 Ratio	24.3	10.7	2.2	44.3
CD3 HLA-DR Cells	185.2	107.6	22.4	58.1
CD3 CD16-56	142.2	147.2	30.7	103.5
NK Cells	477.8	211.9	44.2	44.3

m= mean; sd= standart desviation; sm= standart error; CV=constant of variation
$p<0.05$

TABLE VI

	Sample		Normal		Sig	p
	m	sd	m	sd		
CD19 Cells	9.5	3.1	14	4.2	S	p<0.001
CD3 Cells	68.8	5.9	73	6.5	S	p<0.01
CD4 Cells	43.2	7.5	44	7.6	NS	-
CD8 Cells	41.1	9	33	7.4	S	p<0.001
CD4/CD8 Ratio	1	0.3	1.4	0.6	S	p<0.001
CD3 HLA-DR Cells	8.1	3.7	11.5	2	S	p<0.001
CD3 CD16-56 Cell	6	4.7	5	0.5	NS	-
NK Cells	21.9	8	14	6	S	p<0.001

Sig = Statistically Significant; S = significant ; NS Non significant

TABLE VII

	Value(n)	Value(n)	Sig	p	Param	P 50
Locus Control	<10 (10)	>10 (13)	NS	-	-	10
STAI	<4 (14)	>4 (9)	NS	-	-	3
Social Support	<24 (11)	>24 (12)	NS	-	-	25
SLEC	<2.1(12)	>2.1(11)	S	p<0.05	CD4+	2.05
Age	<32 (11)	>32 (12)	NS	-	-	32
Flight Hours	<2000(11)	>2000(12)	NS	-	-	2000

n = number of subjets ; P50 = Median

TABLE VIII

Lineal and Polinomic Regresion Values obtained from the sample

	Lineal	Polinomic	R
L.Control / T cell activated	S	S (1st grade)	0.41*
SLEC / CD4 Cells	NS	S (4th grade)	0.70*
L.Control / CD4 Cells	NS	S (2nd grade)	0.58*
Social Support / NK Cell	NS	S (3rd grade)	0.68**

R = Regression ; *p<0.05 ; **p<0.01

TABLE IX

-Air Combat and Exercises(last two months)...........	100%
-Instructor Flights...................................	34.7%
-0-2 take-off / landing / day.........................	91.3%
-Flying time period less than 2 hours.................	95.6%
-Less than 40 hours flying time /month...............	100%
-Flight incident occassionally........................	60.8%
-Low level flight (quite often).......................	65.5%
-10-30 days / month TDY (off home)....................	30.4%
-Flight Plan reviewed at last minute..................	47.8%
-Overload of administrative duties off squadron.......	82.6%

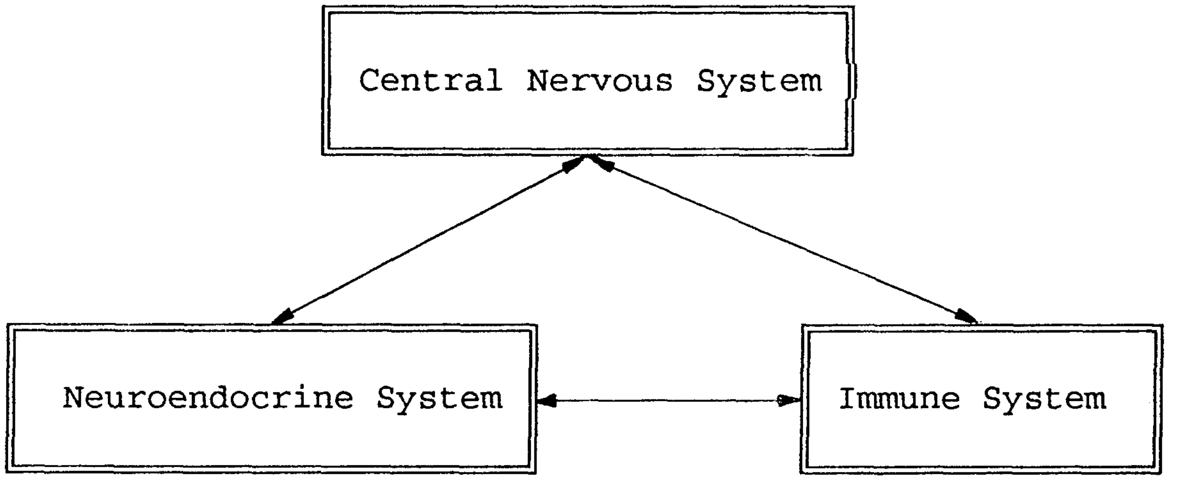


TABLE X

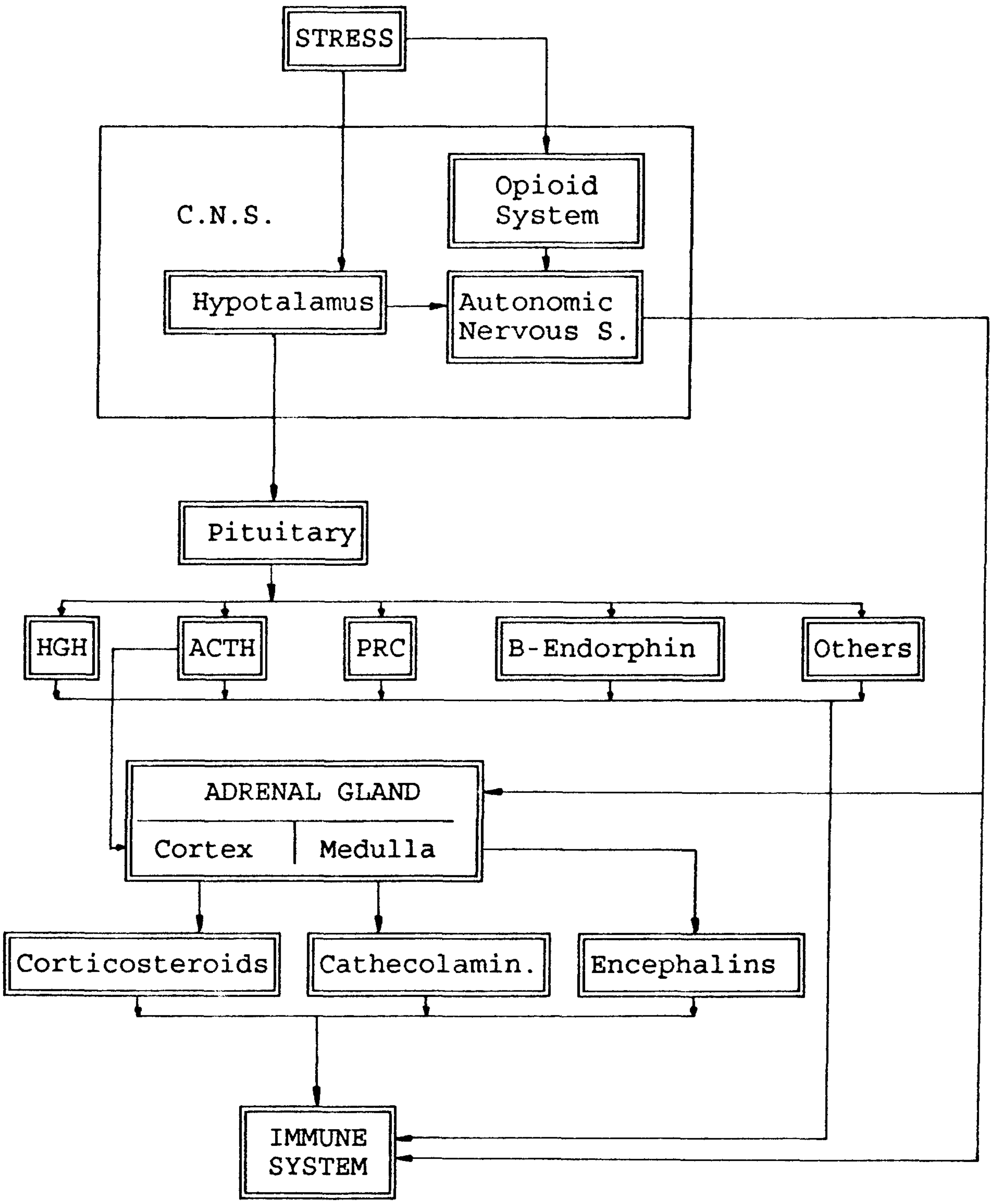
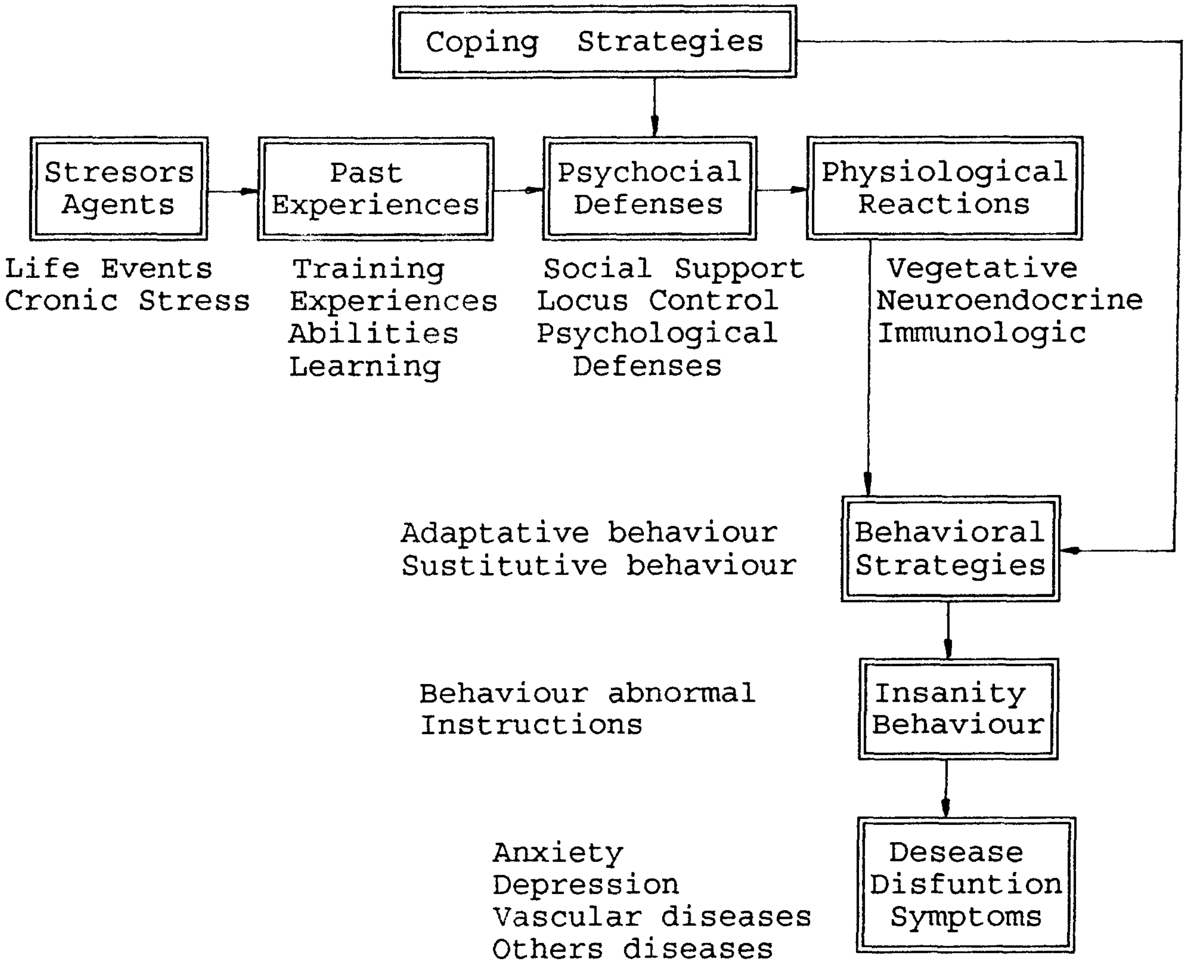
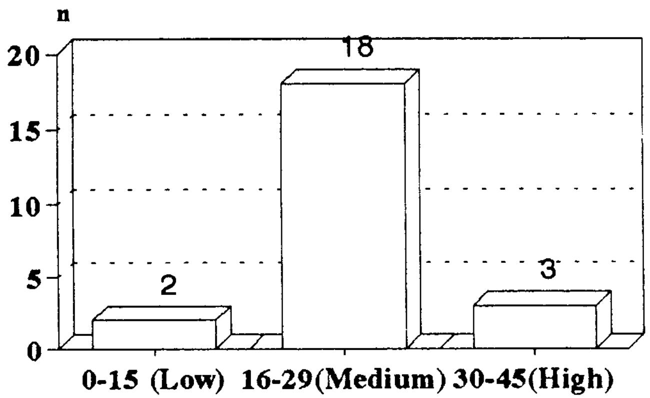

STRESS
C.N.S.
Opioid System
Hypotalamus
Autonomic Nervous S.
Pituitary
HGH
ACTH
PRC
B-Endorphin
Others
ADRENAL GLAND
Cortex
Medulla
Corticosteroids
Cathecolamin.
Encephalins
IMMUNE SYSTEM

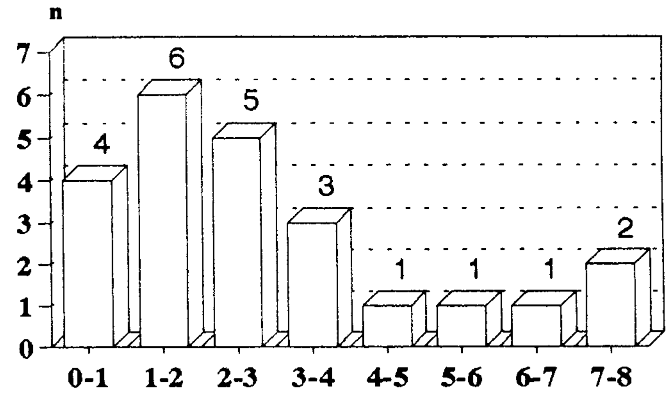
TABLE XI


Coping Strategies
Stresors Agents
Past Experiences
Psychocial Defenses
Physiological Reactions
Life Events
Cronic Stress
Training
Experiences
Abilities
Learning
Social Support
Locus Control
Psychological Defenses
Vegetative
Neuroendocrine
Immunologic
Adaptative behaviour
Sustitutive behaviour
Behavioral Strategies
Behaviour abnormal
Instructions
Insanity Behaviour
Anxiety
Depression
Vascular diseases
Others diseases
Desease Disfuntion Symptoms

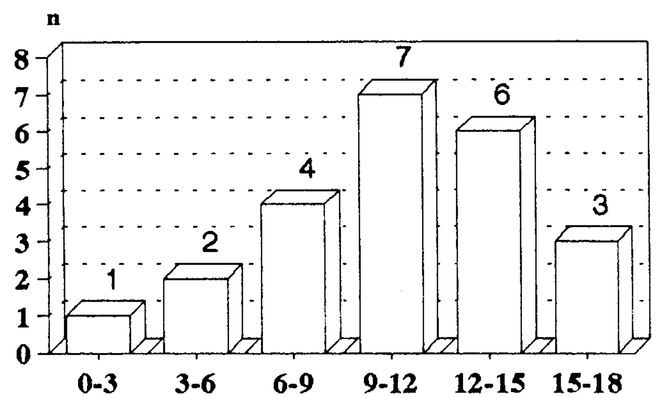
SOCIAL SUPPORT
California Mental Health Questionaire

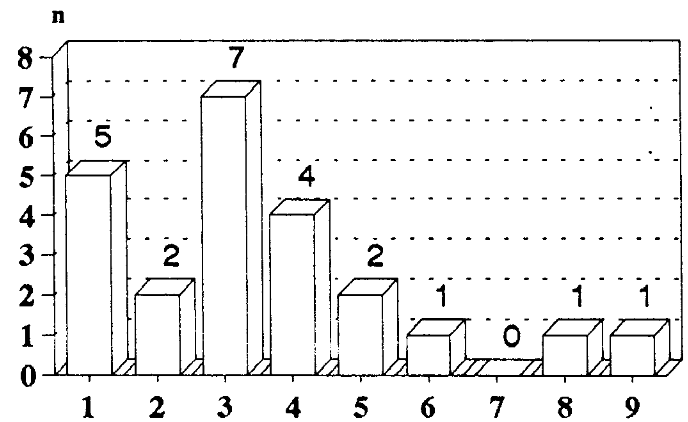


STRESFULL LIFE EVENTS QUESTIONAIRE(SLEQ)
JJ CASTILLON Questionaire



LOCUS OF CONTROL
ROTTER'S QUESTIONAIRE





An Analysis of Stress and Coping Factors on Air Crew during Emergency Medical Service (EMS) Helicopter Operations.

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Summary : *The air ambulance service represents a field of operations where the crewmembers encounter situations which demand quick decisions and immediate action and where time limitations are frequent. Missions flown include diverse tasks such as inter - hospital transportation of patients as well as search and rescue operations. The operational stresses of this kind of service are plentifold and include both physical and psychological factors. Additional stressors include mission type, weather-conditions and harsh terrain. Previous studies on stress and performance indicate that risk prone situations have a tendency to increase the crew's level of activation and will ultimately influence their performance.*

The purpose of the current study was to see whether one can observe differences in the crewmembers' physiological activation relative to mission type, crewmember's area of responsibility and individual psychological coping strategies and use of defense mechanisms.

The initial study consisted of 31 male crewmembers from the Norwegian Air Ambulance Service distributed among helicopter pilots, medical doctors and rescuemen. To assess physiological activation, plasma consentrations of cortisol were measured directly after mission completion as well as 24 hours later for controlling purposes. In addition, a psychological assessment was administered for an evaluation of general anxiety levels, coping strategies and defense mechanisms as well as subjective evaluations of the mission flown.

1. Introduction

The helicopter is a demanding workplace. Despite recent advances in rotor-wing development; ergonomically and technically these aircraft still lag behind compared to their big brother, the fixed - wing aircraft (Adams, 1989). Nevertheless, due to their flexibility and maneuvering qualities, choppers are extensively used in numerous areas such as the air ambulance service. Transportation of patients, often multi-traumatized, far from prepared landing-sites and in weather conditions close to minima, tell of a service saturated with imaginable operational hazards.

Flying includes a series of possible stressors, both physical and psychological and places great demands on operator performance. The physical stressors are easiest to recognize : Noise, vibration and temperature variations, while the psychological stressors such as work/rest scedules, biological rhythm changes and emotional strains due to operational factors are not so easy to define. The crew of the air ambulance service experience, in addition, stressors such as marginal weather conditions, hazardous terrain, time restraints and traumatized patients.

Stress research has focused its attention on individual physiological changes during performance. It is well documented in stress litterature that our emotional reaction to different situations is reflected in our neuroendocrine and adrenal system (Værnes, Myhre et al, 1988, Vassend, 1989). These studies demonstrate hormonal as well as immunological changes. In order to cope with different situations and the demands they place on us, our hormonal activity will change, reflecting the human accomodative ability. In other words, our coping strategies are reflected in hormonal activity.

Studies conducted on parachutists (Ursin, Baade & Levine, 1978), marine deep sea divers (Værnes & Darragh, 1982), and fighter pilots (Værnes et al., 1988) all show significant correlations between degrees of situational strain on one side and physiological activation and psychological reaction on the other. What is important to bare in mind, however, is that any strain experienced, is the result of an individual evaluation of the situation at hand. Experiences, always subjective in nature, are reflected in physiological reactions that differ in magnitude despite similar operational contexts (Hamilton & Warburton, 1979, Ursin & Ollf, 1992). In turn, physiological reactions due to strain, are influenced by individual coping strategies and defense mechanisms. Individual coping strategies and

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defense mechanisms, therefore, function as guidepoles for the operator through the evaluation process where previous experience and knowledge of similar situations play a major role (Lazarus & Folkman,1984).
The purpose of the current study was to seek answers to the questions of whether a) there is a difference between the different crew categories' physiological reaction following an ambulance mission by helicopter, and whether b) psychological factors can explain why some crewmembers experience greater strain than others shown as increases in cortisol exretion.

2. Method

Subjects : 33 crewmembers from the Norwegian Air Ambulance Service participated in the study, representing approximately 30 % of the population. Each crew consists of a helicopter pilot, a medical physician and a paramedic. Data collection was mainly concentrated throughout the spring and summer months.

Instruments : Spielberger Trait Anxiety Inventory (STAI-TRAIT) was administered for an evaluation of individual differences in anxiety reactions to threatening situations. Millon Behavior Health Inventory (MBHI) was chosen to screen basic coping strategies and Plutchik Life Style Index (LSI) for a description of individual defense mechanisms. For the purpose of this paper, evaluations of LSI will not be included.

Physiological tests : Hormonal activity was measured through the sampling of plasma concentrations of cortisol. The sampling was accomplished by the base doctor or nurse, and sent on for analysis. Cortisol was chosen rather than catecholamines and immunoglobulins due to design conciderations as well as due to hormonal half lives.

Experimental design : The blood samples were collected in 3 series. 1) Basic measurements were taken at 0900h before breakfast, 2) measurements were taken directly following completion of the mission and again 3) 24 h later for controlling purposes. An evaluation form was administered after each mission for a subjective assessment of the mission from each crewmember. Samples were sentrifuged, pipetted and frozen for storage. Analysis of the samples was undertaken with Fluorescence Polarization Immunoassay technology by certified biochemists.

3. Results

a) Physiological measures

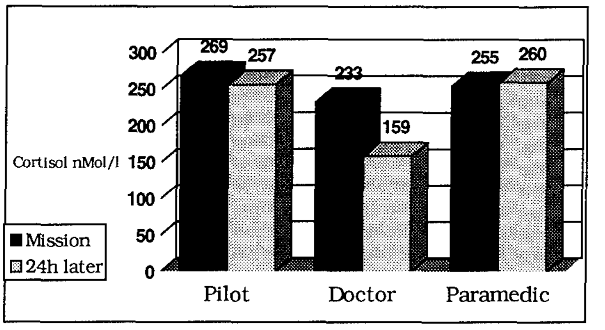

Figure 1. Cortisol excretion and changes in cortisol level directly following mission completion and 24h later, distributed by occupational category.

In viewing the physiological data, they indicate that hormonal activity does vary from the measurement taken following the mission to the control measure taken 24 h later, although this difference in activity is not statistically significant.

Due to the fact that sample-size per occupational category is low, statistical power decreases and conclusions will be tentative at this time. Despite this obvious lack of statistical power in the methodological design of the study, certain tendencies are clearly drawn from the current sample. As the figure indicates, there is a clear tendency towards increased hormonal activity after the mission for the pilot and doctor sample, followed by a marked reduction in this activity at the control measure. A rather interesting tendency is shown in the bar representing the paramedic sample. This group shows the opposite tendency compared to the other two groups, a decrease in hormonal activity following mission completion compared to the control measure 24 h later.

The crew were asked after each mission completion about the degree of strain they experienced themselves during the mission. This question was meant as an indication on the relation between subjective experiences and objective, physiological reactions.

	Levels of cortisol after mission completion	Changes in cortisol at control measure
Physical strain	0.31	0.19
Mental strain	0.36 *	0.29

Table 1. Correlation coefficients between levels of cortisol and subjective ratings of physical and mental strain. Significant correlations are marked (*).

The analysis reveales a positive correlation between levels of cortisol after mission completion and subjective experiences of physical strain ($r = 0.31; p = 0.09$). Significant correlations between levels of cortisol after mission completion and subjective experiences of mental strain ($r = 0.36; p = 0.05$) were observed as well. However, correlations between levels of cortisol at the control measure and subjective evaluations of physical and mental strain were weak statistically, although the relation is positive in nature.

b) Psychological measures

Turning our attention to the results from the psychological test battery, we found that they aided in a clarification of the physiological results, which in turn lends further support to the importance of including both physiological and psychological data in scientific research for an indepth understanding of the processes underlying human behavior.

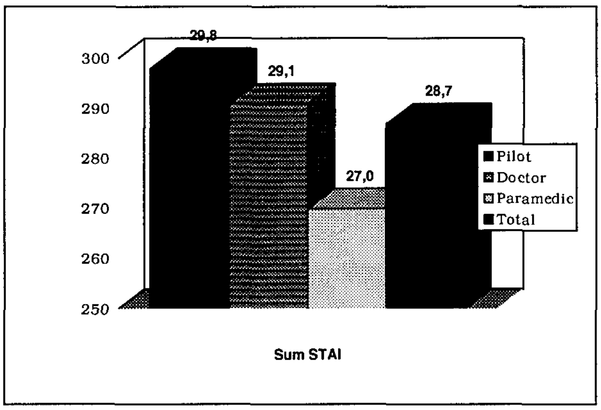

Figure 2. Mean sum scores on STAI-TRAIT, distributed among occupational categories, n= 29.

The data representing STAI TRAIT show a mean value of 28.7 (1sd =3.6) for the sample group, a mean score somewhat lower than for F-16 fighter pilots, 31.4 (Værnes et.al., 1989) as well as for similar studies conducted elsewhere using male samples (Hildal & Solbue, 1986).

The chart shows a significant difference between sum scores for the pilot sample (29.8 ;1 sd = 3.8) compared to the sum score for the paramedics (27.0; 1 sd = 3.2). As for the doctor sample their sum scores (29.1; 1 sd = 3.6) differ from both pilot and paramedic, although these differences are not statistically significant.

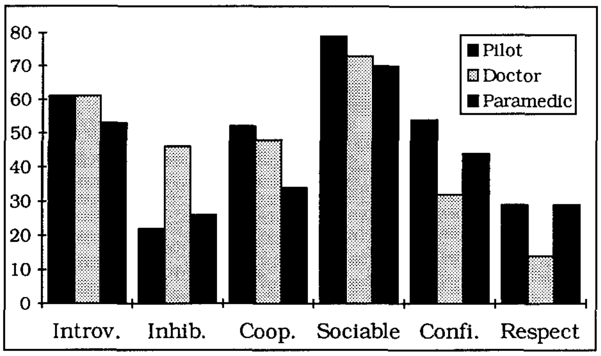

Figure 3. Mean scores on Millon Behavior Health Inventory, distributed among occupational categories.

For the MBHI test results, the following chart shows a relatively high sum score for the coping style ' sociable ' and 'introversion ', a result in compliance with earlier findings on pilot samples (Myhre, in press).

A rather surprising aspect from the current material is shown in the bar representing the coping style ' respectful '. Contrary to general belief, we found low sum scores for all occupational categories on this coping style, indicating a tendency to disregard organizational rules and procedures as well as a lack of general responsibility. Further analysis of this material did show that approximately 17 % of the total variance in hormonal activity was explained by variations in the coping style mentioned. Viewing the material as a whole, the psychological tests accounted for nearly 42 % of the variation in hormonal activity, leaving more than 50 % of the variance unaccounted for. Further analysis has shown that operational factors, such as time of day, weather condition and mission type are important contributors to the variation in physiological activation.

4. Discussion

The current results show a general increase in hormonal activation following a mission segment, further documented by a change in this activation at the control measure 24 hours later. These changes are, however, not statistically significant. By including psychological conditions, a more precise picture accumulated, accounting for some of the variance between the two physiological measures, before and after the mission flown.

The air ambulance service represents a complex workplace. One day on duty is not similar to another, entailing a major challenge for the crew. As for the missions, they will always differ in several respect, further complicating a standarized description of the service. In addition, due to the relative lack of regular routines, an acceptable continuity in the data collection will depend on the ability to control variables that may influence the results, not normally termed an easy venture in field research. The results, naturally, reflect this complexity.

The paramedic sample reacted with decreased physiological activation during the mission, followed by an increase at the control measure, a finding in contrast to both pilot and doctor sample as well as the general hypothesis for the study. Further studies will attempt to verify this tendency on behalf of the paramedic sample which may be explained by this group's professional background and personal orientation. Paramedic's background in scuba diving and mountain climbing as well as their relative low score on the anxiety scale give rise to a theory of an occupation of sensation seekers, thrilled by the prospect of demanding situations. The air ambulance service is an occupation known for periods of waiting and boredom. For the paramedic population this period of waiting might result in feelings of restlessness and agitation - and therefore accompanying increases in physiological activation.

Due to the fact that the physiological data don't show statistically significant reductions in hormonal activation, several questions arise. One must pose the question as to whether the operational crew actually don't react adequately during missions flown. If the missions are too routine-like in nature, expectations often develop on what the missions demand. Expectations are known to decrease physiological activation due to reduced insecurity and novelty. Decreased activation is a well known risk factor in studies on complacency and inattention and marks a dangerous tendency in any field of work, especially considering negative consequences for safe operations in the air ambulance service.
In addition, the lack of significant results also acts as a reminder of problems encountered as a consequence of conducting research in an operational setting. The amount of variables causing an influence on both physiological and psychological reactions in field settings are plentifold, some of which probably would not have been exposed in laboratory or simulator studies. There are apparent disadvantages in field studies, the most obvious one being the lack of control of intervening variables. However, it is important to bring our knowledge, gained from the controllable confines of the laboratory, to an operational setting, since the stressors actually experienced by the crew often are found exclusively in their relation to the " real world ".

The results did, however, show interesting relations between physiological reactivity and the use of psychological coping styles, lending further support to the theory of an interaction between given situations, individual interpretation and reactivity. The crew consist of professions termed as focused on their job, self assertive and individualistic. Selection procedures in the field of aviation prioritize pilots ability to make independent decisions. Medical doctors score high on traits such as self assertion, autonomy and dominance. In other words, we see a crew with individualistic tendencies. The job in the air ambulance service brings forth the crew's cooperative abilities, while their professional training and background draws at the strings for a " do my own thing " attitude. This dichotomy is illustrated in the current study as elevated scores on both of the incompatible traits ' introversion ' and ' social '.

The results showed surprisingly low scores on the trait ' respectful ', representing a general respect for and adherence to rules and procedures. Interpretation of the data gives an inclination of crewmembers who are willing to take risks and cut corners in order to get the job done. This tendency to make the rules as you go, has been known to prevail in this type of service, which demands quick and unothodox decisions in order to save lives. As a consequence safety has been jeopardized, shown clearly in the higher accident rate for this service as a whole. However, the results do show that the variable ' respectful ' accounts for a relatively high procentage of the variance in hormonal activity, indicating that crewmembers who score high on this trait also show changes in hormonal activity following the assignment. Basic

respect for rules and regulations are regarded as important buffers for safe operations and adhering to them usually reflects in appropriate behavior in given situations. Cutting of corners and untimely improvising often results in weaker performance and greater error rates, illustrated in the human operator as generally higher physiological activation without corresponding reduction following mission completion. Future studies that includes performance measures will be able to verify to a greater extent this hypothesis.

Similar studies have not been conducted in the air ambulance service in Norway. The basis for comparison is therefore thin, and conclusion must be drawn with great care. Further studies are, however, underway, and the results may prove important for a greater understanding of the relation between physiological activation and human mental processing.

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FATIGUE: OPERATIONAL AND CLINICAL ISSUES

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SUMMARY

Despite the great number of papers existing in the literature about the issue of fatigue - both in the clinical medicine and in the human factors field - it actually remains a controversial matter. This difficulty depends on the complexity of defining, recognizing, and measuring the phenomenon of fatigue and of evaluating its effects on performance.
Regarding operational contexts, fatigue may be seen as the objective workload imposed by the task (input load), as the operator effort, or as the level of performance (work output). It is important, moreover, to divide the physical ("central", "peripheral-muscular") from the psychological fatigue. In general terms, physical exhaustion and performance impairments are not necessarily perceived as fatigue; psychological fatigue, instead, has a higher subjective component, a lower correlation with performance decrements, and is less dependent on the level of energy expenditure. Other distinctions may be done between acute, cumulative, and chronic fatigue.
Several attempts have been made to model psychological fatigue and to explain the mechanisms involved in its generation and development. The activation theory, for instance, which takes into account the level of arousal and performance, considers fatigue as the result of functioning longtime at an inadequate level, too high or too low, of information processing. A complex relationship actually exists among the level of arousal, objective measures of performance, the effort assessed using special probes (e.g., cognitive evoked potentials during dual task, increasing complexity tasks), and subjective fatigue.
The relationship between fatigue and performance is also complicated by the many interacting variables such as individual motivation and coping capability.
In air operations, finally, fatigue may be related, in a reciprocal way, to "automated" and "controlled" tasks, with relevant effects on flight safety.
Further efforts of the aeromedical community, therefore, should be directed to both identify early indicators of fatigue and to detect the different types (clinical syndrome or not) of fatigue.
This paper is a review of the current knowledge about operational and clinical fatigue, taking into particular account a recent clinical entity, the chronic fatigue syndrome.

INTRODUCTION

Possibly, at least once in life, everyone in the aeromedical community have faced topics like fatigue, workload, and stress.
A number of specialists - physicians, psychologists, engineers - from both the civil and the military fields in fact have tried to understand and conceptualize these dimensions in order to find sensitive and specific tools to measure them in the operative setting and to apply useful countermeasures against their detrimental effects on performance. Nevertheless, up till now the problem is far from being exhaustively clarified.
This rewiev is aimed to sum up the state of the art about fatigue in the operative and clinical settings and to hypothesize some better diagnostic criteria to be used when approaching "fatigued" aircrew.

CLASSIFICATION AND DEFINITION

In general terms, fatigue can be related to those changes in performance which occur over a period of time during which some part of the organism - sensory, central, or muscular - becames chronically overloaded (1).
In the operational setting, an overlap exists between the concepts of workload and fatigue.
In the clinical setting, a definite disease has recently been identified in which fatigue is the main symptom: the chronic fatigue syndrome (CFS) (2).
In the following sections different aspects, approaches, and models of fatigue are rewieved.

Temporal pattern of fatigue
According to Hartman (3), fatigue can be divided into three types:
- acute, when occurring between two sleep periods;
- cumulative, when resulting from inadequate recovery from periods of acute fatigue;
- chronic, when a psychoneurotic syndrome (neurastenia) occurs in which there is a difficulty to have an active or aggressive behaviour, with a withdrawal from a conflict considered as intolerable. Nowadays, this last definition has been modified with particular reguard to the inability of rest periods to solve the symptom and, with respect to CFS, fatigue has to be

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persistent or relapsing for at least 6 months (4).

Physical (physiological) fatigue

A first level can be individued in the muscular fatigue. This term refers to an altered omeostasys of the muscular tissue following prolonged contraction, which leads to a progressive lost of function (5).

This condition, however, is not confined to peripheral structures, but involves both nerves and the central nervous system (CNS) so that a reduction in the output of the CNS in fact occurs (1).

Other authors, like Grandjean (6), believe that fatigue is a central neurophysiological condition located in the brain stem reticular activation system which is the anatomophysiological substrate of various levels of inactivity, arousal, and activation.

It is evident, anyway, that these physiological aspects are only a part of such a multidimensional phenomenon like fatigue.

Subjective fatigue

Subjective assessments are particularly used in operational studies. In this context, fatigue has been initially seen as a feeling of tiredness (7). Factor analytic studies indicated that this sensation had three major components: 1) bodily tiredness, 2) weaked concentration, and 3) physical complaints and/or psychosomatic disorders (8).

A number of scales have been then developed to quantify subjective aspects; nevertheless, these scales measure also other dimensions such as mental workload, mood, and motivation that are closely related to fatigue. Among the most used rating scales in operational contexts are the School of Aerospace Medicine (SAM) fatigue scale (9), the Profile of Mood States (POMS) (10), and the Subjective Workload Assessment Technique (11). The SAM and POMS scales have been mutuated by the clinical field, togheter with other measures like the Sickness Impact Profile (SIP) (12), the Profile of Fatigue Related Symptoms (PFRS) (13), and the Fatigue Impact Scale (FIS) (14).

The subjective approach, however, globally reveals insufficient to give an exhaustive assessment of fatigue, leading to the need for objective measures too (see below).

Fatigue and performance

Fatigue has been related to performance decrement or skill impairment and referred to the changes in the expression of an activity which occur after a long period of continuing it (15). The activity can be only muscular, only mental, or it can imply a global involvment of cognitive, perceptual, and motor abilities. To better characterize the changes in performance occurring in such particular settings as piloting a plane, Bartlett (16) introduced the concept of "skill fatigue".

Many psychological studies on pilots's performances show that there is a difference between fatigue produced by continued physical work and fatigue produced by a work that do not demand muscular effort, but concentration and a high degree of skill (16). Moreover, physical fatigue can be masked by motivation so that, despite high task demands and energy expenditure (objectively measured by physiological indicators), subjects' perception of fatigue is not exactly related to physical exertion (17). A definite separation between physical and psychological fatigue, however, has more an academic than operational value: both, indeed, are influenced by factors internal and external to the individual like age, state of health, life style, personality characteristics, motivation, kind of work, social factors (18).

Workload

As for fatigue, an unique and exhaustive concept of workload does not exist.

Accordingly to O'Donnell & Eggemeier (19), workload is made up by three related components: task demands (input), operator variables (effort), and response variables (output). This framework is relevant for operational studies of human/machine systems, like those concerning pilot performance.

The different combination of the above mentioned variables may, in case of inbalance between input site and operator state, lead to fatigue and decrement of performance. A number of models have been proposed to explain when and how it happens. They are rewieved in the following sections.

Fatigue and stress

The human stress response consumes a large amount of energy and, in this sense, it is fatiguing. The level of fatigue depends on the duration of stress, more than on its intensity. The lenght of time necessary to come back to a normal level of arousal is an indicator of the severity of fatigue (20).

Like fatigue, stress can be divided into acute, cumulative, and chronic.

The basic reaction to acute stress of every nature is the same: some kind of adaptative or avoidance reaction. Physically, the initial response is the musculoskeletal tension response. Then, a build up of physiological, emotional, chemical factors until some kind of maladaptation occurs (21).

Chronic stress induces 1) pathologies and 2) degrading performance. This second aspect is particularly important in the aviation environment for the risk of aircraft accidents.

MODELS OF FATIGUE AND WORKLOAD

The Energetic Model

This approach focuses on both physical (metabolic) and mental (in terms of information processing capacity) energy expenditure during an effort. If operation is

sustained and cost increases, more and more energy reserves are consumed to the point that a sudden failure in performance occurs (19). The energetic state is influenced by environmental (noise, vibrations, light) and internal (sleep loss, drugs, alcohol, emotions) factors (22).

The Information-Processing and Limited Channel Model (18)
The application of the informatic theories to psychology led to the construct of this model (23). It considers the human as a processor of information. The amount of information that each individual can process, however, is not inexaustible because the processor has a limited channel capacity. If the mental workload increases, it is absorbed by the reserve channels capacity, until the demands of information processing of the task exceed the available reserve capacity. Many environmental stressors, moreover, affect performance because they charge the attention capability of the operator with a further demand, leading to a global consumption of reserve resources. At this point, fatigue increases as a linear function of the mental workload and degradation of performance occurs.
Another aspect of this model takes into account the information-processing threshold. The same U curve that regulates the relationship between the level of arousal and performance can be applied to the information-processing model. If the level of information-processing is too high or too low, the performance decreases.

MEASURES OF FATIGUE, WORKLOAD, AND STRESS

The overlap that exists between concepts of fatigue, workload, and stress is confirmed when considering their objective measures. These are mainly physiological measures in that very similar mechanims underlie the bodily responses to fatigue, workload and stress.

Cardiac measures
- sinus arrhythmia (24)
- heart rate and heart rate variability (25)

Ocular measures
- pupillometry (26)
- blink rate (27)
- electrooculogram (28)
- critical flicker fusion (29)

Neurophysiological measures
- EEG (30, 31)
- polysomnography (32)
- evoked responses (33, 34)
- Emg (35)

Biochemical measures
- urinary catecholamines and cortisol (36)
- markers of immune response (37)

These indicators have been widely and usefully employed in both laboratory and field studies.

FATIGUE IN THE OPERATIONAL SETTING

Air operations often imply fatiguing conditions due to irregular rest-activity patterns. Long haul flight operations involve night flying, crossing of multiple time zones, and monotonous activities all leading to disruption of circadian rhythms, sleep loss, fatigue, and dangerous decrements of performance. Recently, Wegman et al. (38) have studied crew members of a German airline flying on two consecutive nights with short layover. The Authors have found a sleep loss of 9.3 hours with spontaneous microsleep, EEG signs of drowsiness, lowered motor activity, and increased subjective fatigue. Night duty, accumulated sleep loss and long time on task without breaks have mainly accounted to fatigue. These results point out the issue of flight time limitations. Rosekind et al. (39) have proposed some topics for future research about fatigue in operational settings. They have stressed such important factors as individual adaptability to irregular work hours, napping strategies, and time on task limitations according to specific activities to be taken into account to improve effectiveness and safety of air operations.

FATIGUE IN THE CLINICAL SETTING: THE CHRONIC FATIGUE SYNDROME (CFS)

Fatigue is the most prevalent symptom of a recently isolated clinical syndrome. the CFS (2). The case definition was created in 1988 by the United States Centres for Disease Control (40). A set of similar criteria was then developed also in Australia (41) and in the United Kingdom (42). The case definition was reviewed in 1992 (43). No physical findings or laboratory testing were deemed confirmatory of the diagnosis. To meet the case definition for CFS, a case must fulfil both major and minor criteria.

Major criteria:
1. New onset of persistent or relapsing, debilitating fatigue in a person without a previous history of such symptoms that does not resolve with bedrest and that is sever enough to reduce or impair average daily activity to less than 50% of the patient's premorbid activity level for at least 6 months.
2. fatigue that is not explained by the presence of other evident medical or psychiatric illness.

Minor criteria

At least 6 symptoms plus at least two signs, or at least eight symptoms of the list below:

1. Mild fever. 37,5°-38,5°.
2. Sore throat.
3. Painful adenopathy (posterior cervical or axillary)
4. Generalized muscle weakness.
5. Myalgias.
6. Prolonged generalised fatigue (>24 h.) after previously tolerated levels of physical activity.
7. Generalized headaches.
8. Migratory arthralgia without swelling or redness.
9. Neuropsychological complaints.
10. Sleep disturbances.
11. Main symptom complex developing over a few hours to a few days.

Physical signs:

1. Low-grade fever.
2. Nonexudative pharyngitis.
3. Palpable or tender anterior or posterior, cervical or axillary lymph nodes.

CFS was named in the past as myalgic encephalomyelitis, chronic mononucleosis, post-viral asthenia, post-viral fatigue syndrome, chronic Epstein-Barr virus (EBV) infection, post-infectious neuromyasthenia (PIN), fibromyalgia or fibromyositis.

It is not easy to obtain epidemiological data because of the wide overlapping between CFS and other similar entities (mainly psychiatric disorders). When diagnosis criteria are fulfilled, a minimum prevalence rate of 7.6 cases per 100,000 can be considered (44), even if Buchwald et al. (45) have recently found an estimated crude point prevalence ranging from 75 to 267 cases per 100,000 .

Causative agents (46)

The aetiology of CFS is not yet clearly established. Many different aetiologic agents could implied, namely viruses.

EBV has been hypothesized as causative of CFS; there is no evidence, however, of an increased viral excretion of this virus in the group of patients with CFS and it seems to be a little evidence for EBV reactivation in this group. Other viruses may trigger the CFS by activating some common mechanism, possibly related to the immune system: enteroviruses, human herpesvirus 6 and 7, retroviruses (47). But the question remain if viruses are primary agents or their are reactivated after the onset of CFS. The same question concern the immunologic abnormalities: are they primary or secondary?

Clinical aspects of CFS (48)

The majority of patients (mean age: 37 yrs, range: 11-60) report a sudden onset of the illness, with an initial flulike, characterized by fever, sore throat, cough, myalgias, and fatigue. Whatever the nature of the onset, the illness becames chronic. A peculiar symptom is an exhagerated postexertion malaise, with pain and weakeness of involved muscles and a a striking exacerbation of the symptomatology. The patient medical hystory shows a high frequency of atopic or allergic illness (50% of cases).

Abnormal reports at the physical examination are found in 15-50% of the cases: fever, low basal body temperature and posterior cervical adenopathy. Abnormal haematologic tests are found in 15-50% of the cases.

Evaluation of CFS

The CFS is difficult to evaluate because, maybe with the exception of the actimetric technique, no objective measures of disability exist. Physical examination findings or laboratory testings are not considered confirmatory for the diagnosis. Few instruments for assessing fatigue, mood disturbances, functional status, sleep disorders, global well-being, and pain exist, and the clinician must rely only on patient's self-report instruments (12-14).

Differential diagnosis

a. Psychyatric disorders (49)

1. Major depression. Differential diagnosis is difficult due to the similarity of diagnosis criteria. 76% of cases of CFS fulfill the DSMIII-R criteria for major depressive episode (50).
2. Other psychiatric diseases: somatization disorders, panic disorders, dysthymia, bipolar disorders.

b. Sleep disorders (51).

c. Somatic diseases provoking chronic fatigue (52).

1. Unsolved viral infections (Mononucleosys, Citomegalovirus, Borrelia, Lyme disease).
2. Circulatory diseases (hypertension, congestive heart failure).
3. Uraemia, renal diseases.
4. Endocrine disorders (myxoedema).
5. Iatrogenic disordres. Drugs.
6. Bronchial and pulmonary diseases.
7. Haepatic disorders.
8. Rheumatoid arthritis.
9. Diabetis.
10. Neurological disorders.
11. Cancer.

To exclude some organic causes of fatigue it has to be checked (53):

a. Absence of infections
b. A normal blood pressure
c. Normal endocrine function
d. Adequate oxygenation of the blood
e. Normal renal function
f. Absence of collagen diseases

In conclusion, the CFS is an heterogeneous disorders, both in terms of clinical presentation (duration and polymorfism of symptoms) and in terms of proposed biological markers.

Despite several possible viral aethiologies have been suggested, serologic markers are not actually isolated. No evidence exists of a single pathogenetic mechenism of CFS. It is also possible that CFS is not a single clinicopathological entit, but the result of multiple diseases process (54).

CONCLUSIONS

It is evident that fatigue is a broad dimension, involving a number of aspects, and its global evaluation is difficult from both the operational and clinical point of view. The aeromedical community must take into account that aircrew can derive fatigue from several causes, not always related to operative activities. In particular, the available medical knowledge concerning the CFS suggest to include this syndrome in the evaluation of people complaining of fatigue. It could be a challenge to aeromedical services, from both the cultural and financial point of view, to introduce such new issues in approaching fatigued personnel. Nevertheless, it is advisable to pay more attention to differential diagnosis in order to improve countermeasures and treatments. Figure 1 shows a possible decisional tree to be used in the evaluation of subjects complaining of fatigue.

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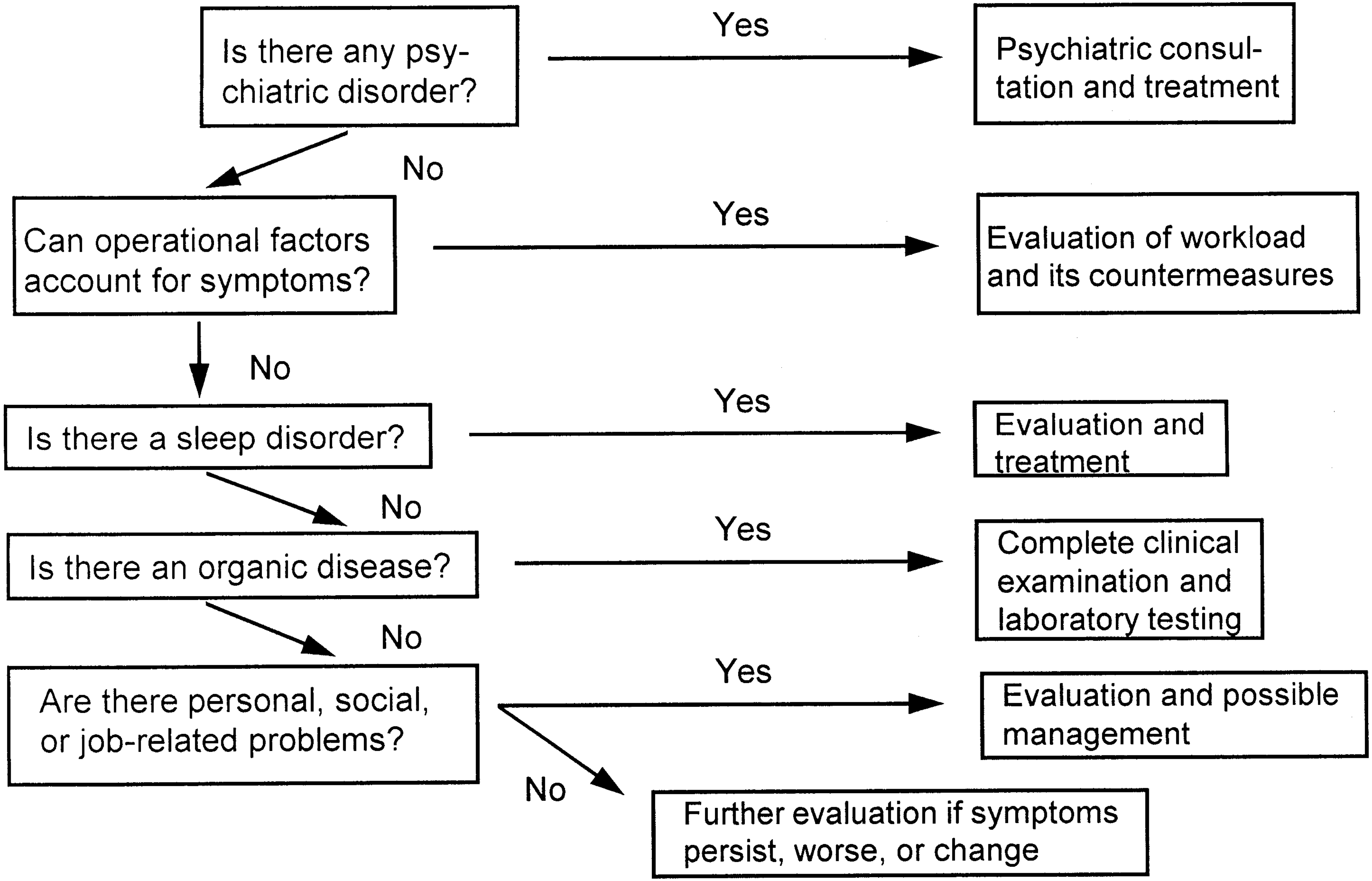

Fig. 1 - Proposal of a diagnostic decisional tree for fatigued subjects.

SLEEPINESS DURING AN ACUTE NIGHT SHIFT: NEUROPHYSIOLOGICAL CORRELATES AND EFFECTS ON PERFORMANCE

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SUMMARY
Nocturnal sleepiness is a common complaint suffered from night shift workers, especially in condition of abrupt shift of the wake-sleep cycle. It is evident, therefore, that monitoring the presence of sleepiness and its effects on performance is of primary importance to the aeromedical community. In this study we evaluated the effects of a laboratory simulation of acute night shift on sleepiness, vigilance and performance, using Maintenance of Wakefulness Test, Multiple Sleep Latency Test and three pencil and paper tests: Digit Symbol Substitution Test, Deux Barrage Test and Letter Cancellation Task. Results showed that the ability to maintain wakefulness and to perform visuo-attentive tasks is substantially spared during the night, despite Multiple Sleep Latency Test and performance on Letter Cancellation Task reveal, respectively, increasing sleepiness and degrading performance on more complex and monotonous task.

INTRODUCTION
Sleepiness is a very common, natural experience of everyday life. However, it becomes a dangerous neuropsychophysiological limitation in a number of conditions that require an optimal level of performance. This topic is of particular concern in the aviation environment: sleep deprivation, alterations of sleep structure, the length and boredom of tasks, and unusual hours of work all contribute to increase sleepiness and thus to reduce performance in aircrews. It is evident, therefore, that monitoring the presence of sleepiness and its effects on performance is of primary importance to the aeromedical community.
Maintaining the effectiveness of aircrew during intensive and sustained operations requires the understanding of how the performance of individuals is modified by unusual patterns of work and rest. The main factors which influence performance during duty periods and sustained operations are the time since sleep, the time of day, and the time on task (1). The combination of these three factors contributes to desynchronization of biological rhythms. When these rhythms disturbance affects physical and mental performance, it becomes operationally significant (2). To improve performance and to effectively contrast the adverse interactions of the afore mentioned factors, one possibility is to use short periods of "prophylactic sleep" (before long periods of work) or to have naps during the work period (1). This sleep can be facilitated and reinforced by hypnotics. This topic is particularly relevant in the management of overnight working periods during sustained air operations.
The assessment of sleepiness in both clinical (e.g. 3) and research (e.g. 4) studies usually is made by means of the Multiple Sleep Latency Test (MSLT). MSLT is based on the idea that drowsiness is close to readiness to fall asleep. But how does the sleepiness measured by MSLT relate to alertness? The Maintenance of Wakefulness Test (5) is a variant of the MSLT which was designed to assess the ability to maintain alertness. The capacity to remain awake may not always be directly related to physiological sleep tendency; these two dimensions, moreover, are differently affected by a previous day-time sleep (6). The relative independence between MSLT and MWT is confirmed by studies done to quantify sleepiness in patients who complain of excessive day-time sleepiness (e.g. 7). The tendency to fall asleep and the ability to remain awake may be different indicators of the alertness state of the subject and may be related in a different way with performance levels.
During an acute night shift, people has to work at the lowest and, respectively, highest point of body temperature and fatigue biological rhythms (8,9). Sleep loss and its interaction with time of day and time on task probably exerts the most critical effects on sustained night operations. It leads to an impairment of the overall level of performance with increasing sleep deficiency. Operational fatigue can enhance the decrease of alertness naturally occurring at night. In such condition, tasks which tend to be repetitive and simple, such as continuous vigilance tests, are sensitive to performance deterioration. As fatigue increases, subjects seem to lose the smooth coordination of the different parts of the task, and attention is less efficiently allocated (10,11).
Behavioral consequences of sleep loss are well known with major decrements occurring in cognitive processes, as measured by complex tasks and vigilance performance (12). Performance has been evaluated by means of several tests which stress different aspects of performance; sometimes, however, these tests imply procedures and devices not easily employable in operational settings. Pencil and paper tests of vigilance can be very useful in the assessment of attentional performance degradation due to sleep loss and/or inversion of the sleep-wake cycle. For example, Opstad et al. (13) reported that performance to the Digit Symbol Substitution Test (DSST) showed a substantial and progressive impairment during long periods (4 or 5

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days) almost without sleep and it was apparent even after 24 hours. These results are important for people whose work depends on reaction speed, visual acuity, motor coordination, and speed of associations.

In order to evaluate more specific variations in tasks involving a great attentiveness, it may be useful the measurement of performance by means of letter cancellation tasks. As a matter of fact, letter cancellation tasks are sensitive to the effect of sleep deprivation (e.g. 14) and to time of day effects on vigilance (15).

In scheduling night-time operation, a short sleep preceding the duty period may be very useful. In this condition, the introduction of rapidly eliminated hypnotics may improve the quality of out-of-phase sleep, while avoiding residual effects during the subsequent wakefulness (16). Such a procedure could be most useful in shift-workers, including long haul flights aircrew (17) and pilots involved in overnight combat operations.

In this contest, Nicholson et al. (18) have examined the possible beneficial effects of an early evening sleep (18.00-22.00) on subsequent overnight performance using brotizolam, a rapidly eliminated hypnotic known to be free of residual effects (16) and effective for night sleep (19). These Authors assessed performance with several cognitive, vigilance and visuo-motor tasks, and with pencil and paper tasks as DSST and 2- and 6-letters cancellation tests. Overnight performance to both test was improved in all subjects who have had the "prophylactic" sleep, as compared to the performance of the group without a previous evening sleep. It would appear that relatively short periods of sleep have a beneficial effect on subsequent performance, even in the absence of preceding sleep debt, attenuating the circadian fall in night performance. In addition, pencil and paper tests of vigilance seem to be effective in detecting such performance deterioration due to sleep loss and circadian factors.

Aim of this study was to evaluate the effects of a laboratory simulation of acute night shift on sleepiness, vigilance and performance.

METHOD

Subjects

Ten males, ranging from 23 to 56 years of age (Mean= 33.5 ± 9.4), served as volunteers in the study. All the subjects had previous experience in sleep lab procedures. All of them performed two behavioral tasks, the *Digit Symbol Substitution Test* (DSST) and the *Deux Barrages Test* (DB) and seven of them (ranging from 23 to 56 years of age; mean= 30.6 ± 5.3) performed a *Letter Cancellation Test* (LCT); eight subjects (ranging from 23 to 56 years of age; mean= 33.7 ± 10.2) underwent to both *Maintenance of Wakefulness Test* (MWT) and *Multiple Sleep Latency Test* (MSLT). At their homes, subjects were asked to fill in a daily sleep questionnaire upon final awakening in the morning, and to do this for one week before the experimental session. Only subjects who reported no sleep, medical, or psychiatric disorders were included in the study.

Polygraphic recording of sleep

EEG was recorded from four monopolar locations (C3-M2, C4-M1, O1-M2, O2-M1); EOG was recorded from the left and right outer canthus, both referred to FPz; EEG and EOG parameters were recorded with a time constant of 0.3 sec. Low pass filters were set at 30 Hz. Submental electrodes were employed for recording bipolar EMG, with a time constant of 0.03 sec. The impedance between electrodes was kept below 10 Kohms. All recordings were in AC. For data collection a polygraph "VEGA 24 - OTE BIOMEDICA" was used. Central EEG (C3-M2), EOG from both eyes and EMG were used to visually score sleep stages, using the standard Rechtshaffen and Kales (20) criteria.

Polygraphic measures of sleepiness

Multiple Sleep Latency Test (MSLT). Sleep latencies were recorded with the subjects lying in bed and attempting to fall asleep, using the standard procedure (21). The subjects were awoken immediately after two consecutive 30 sec epochs of any stage of sleep, and the score was taken as latency to the first epoch of any stage of sleep. If sleep onset did not occur, a latency of 20 mins was used for data analysis.

Maintenance of Wakefulness Test (MWT). The MWT (5) was developed to evaluate the capacity to remain awake. The MWT protocol required the subjects to sit in a comfortable, high-backed chair, with their eyes closed, in a darkened room with instructions to "remain awake". Sleep onset definition and termination criteria were the same used in the MSLT procedure.

Behavioral tasks

Three pencil and paper vigilance tasks were used.

Digit Symbol Substitution Test (DSST). This is a subtest of the Wechsler Adult Intelligence Scale (WAIS) (22) involving cognitive, perceptual and motor ability. The DSST pairs the digits 1-9 with nine symbols; the task is to enter the appropriate symbols into the empty square beneath the digit. Two parallel forms were used. The subject's score is determined by the number of items correctly completed in a short time, typically 90 seconds; in this study four minutes were fixed as time completion limit.

Deux Barrage Test (DBT). This task (23) required subjects to cancel, as fast and accurately as possible, two symbols within a 40x25 matrix made by eight similar symbols (each of them is repeated 125 times), printed on an A3 paper sheet. Each symbol is made by a 3 millimeters square and by one segment crossing each other square's angle or side. Ten minutes were fixed as time completion limit. Five parallel forms were used. Number of hits, number of misses, number of false positives and completion time were used as dependent variables.

Letter Cancellation Task. The LCT (14) required subjects to cancel, as fast and accurately as possible, three target letters within a 36x50 matrix of capital letters printed on an A4 paper sheet. Every target appeared 100 times in a random sequence; for each matrix 300 hits were possible. Five parallel forms were used. Number of hits, number of misses, number of false

positives and completion time were used as dependent variables.

Procedure

Subjects arrived in the sleep laboratory at 8.00 a.m. and spent 24 hours in the laboratory. After application of the electrodes, participants were tested to assess the baseline performance in several tasks evaluating sleepiness, vigilance or performance during diurnal wakefulness. At the end of this test condition, subjects tried to sleep during the day. During the night they underwent the same neurophysiological tests that were administered during the day. Each test was performed every two hours and for four times starting from 11.00 p.m. In every condition, all the tests were given individually and under an equal experimental setting.
We used a double-blind, balanced paradigm with the hypnotic temazepam (20 mg) and with placebo (for more details see: 24), but in the present paper only measures about MSLT, MWT, DSST, DBT, and LCT obtained during the placebo condition are reported.

Data analysis

We considered as dependent variables the sleep latencies on MWT and MSLT, the number of hits on DSST, and the number of hits, the number of misses, the number of false positives and the completion time on both DBT and LCT. For MWT and MSLT, a repeated measure ANOVA *Test* (MWT, MSLT) by *Time of day* (11.00, 1.00, 3.00, 5.00) was performed. For performance data, ANOVAs considering the *Time of day* as within factor were carried out for every dependent variable. To normalize the distribution of the data, both polygraphic and behavioral measures were submitted to natural logarithmic (ln) transformation.
Finally, for every data, intercorrelations (Pearson correlation) among polygraphic and behavioral measures were performed.

RESULTS

Regarding MWT and MSLT, ANOVA showed a significant effect for *Test* ($F_{1,7}$= 19.64; $p<.003$), with shorter mean latencies on MSLT (7 mins) than on MWT (15 mins) and for *Time of day* ($F_{4,28}$= 5.51; $p<.002$), and a significant interaction ($F_{4,28}$= 4.06; $p<.01$), with planned comparisons showing a significant linear trend during the night only for MSLT ($F_{1,7}$= 23.37; $p<.002$; Fig. 1). Both DSST and DBT showed no time of day effects. For LCT, the number of hits ($F_{4,24}$= 2.8; $p<.05$), the number of misses ($F_{4,24}$= 3.8; $p<.03$), and the completion time ($F_{4,24}$= 2.75; $p<.05$) showed a decrease of performance during the night. Planned comparisons performed on nocturnal sessions indicated a quadratic trend for both the number of hits ($F_{1,6}$= 6.6; $p<.04$; Fig. 2) and the time of completion ($F_{1,6}$= 7.2; $p<.04$; Fig. 3) and a linear trend for the number of misses ($F_{1,6}$= 15.7; $p<.01$; Fig. 4). Table 1 shows means and standard deviations of sleep latencies on MWT and MSLT and of dependent variables assessing performance on DSST, DBT, and LCT.
Pearson correlation was used to evaluated the concordance among polygraphic and behavioral measures. Table 2 shows intercorrelation matrix.

Table 1. Mean sleep latencies (±SD) on MWT and MSLT and means performance (±SD) on LCT, DSST and DBT.

TEST	MEANS				
	Baseline	**Nocturnal 1**	**Nocturnal 2**	**Nocturnal 3**	**Nocturnal 4**
MWT (sleep latency)	14.44 (6.30)	16.50 (6.48)	15.87 (7.49)	15.69 (7.46)	12.56 (7.96)
MSLT (sleep latency)	7.06 (6.49)	11.75 (4.42)	7.87 (7.74)	5.75 (7.31)	3.44 (4.30)
LCT (Hits)	265.4 (36.9)	267.6 (17.7)	263.3 (37.4)	265.0 (42.0)	245.0 (57.1)
LCT (Misses)	34.6 (36.9)	32.4 (46.8)	36.7 (37.4)	35.4 (42.0)	55.0 (57.1)
LCT (False positive)	.43 (.79)	.29 (.49)	.71 (1.1)	1.0 (1.0)	1.0 (1.4)
LCT (Completation time)	597.9 (177.5)	531.4 (118.9)	611.4 (129.1)	637.1 (257.3)	557.1 (109.2)
DSST (Hits)	135.6 (32.1)	139.0 (37.8)	137.5 (27.5)	131.9 (29.6)	138.9 (37.7)
DBT (Hits)	234.3 (16.5)	239.5 (8.6)	240.4 (8.0)	236.5 (8.1)	232.1 (20.7)
DBT (Misses)	16.3 (16.3)	10.5 (8.6)	9.8 (7.9)	14.0 (8.4)	18.3 (20.7)
DBT (False positive)	.78 (1.03)	.46 (.96)	.46 (.69)	.78 (1.13)	.56 (.68)
DBT (Completation time)	471.2 (96.1)	441.8 (85.8)	438.2 (91.8)	479.2 (93.0)	466.5 (78.0)

Figure 1. Mean sleep latency on MWT and MSLT.

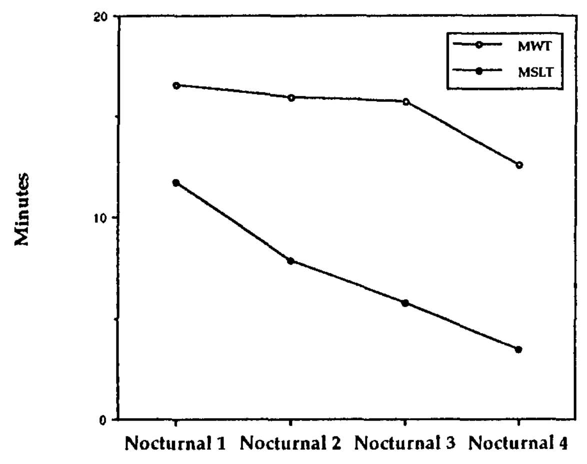

Figure 2. Number of hits in the Letter Cancellation Task.

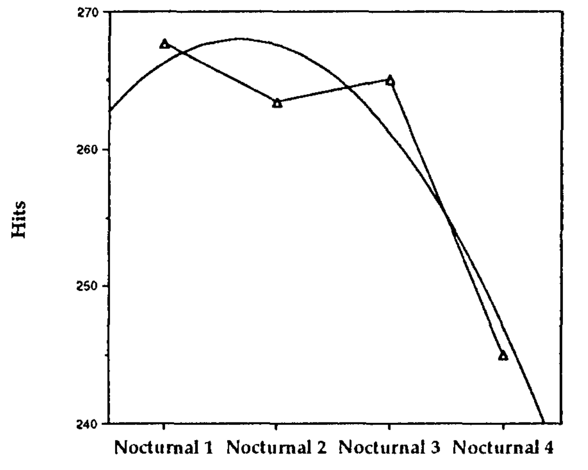

Figure 3. Time of completation in the Letter Cancellation Task.

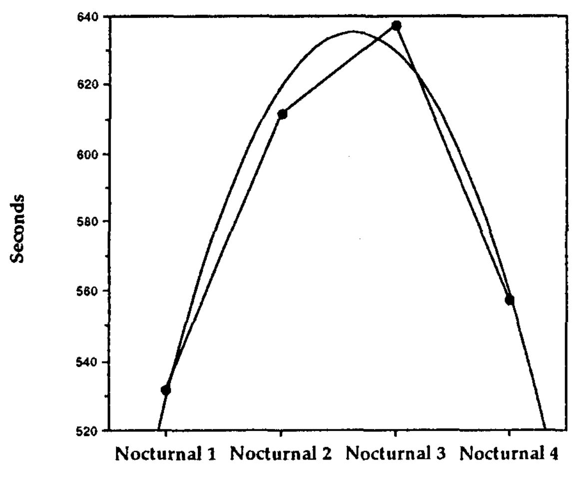

Figure 4. Number of misses in the Letter Cancellation Task.

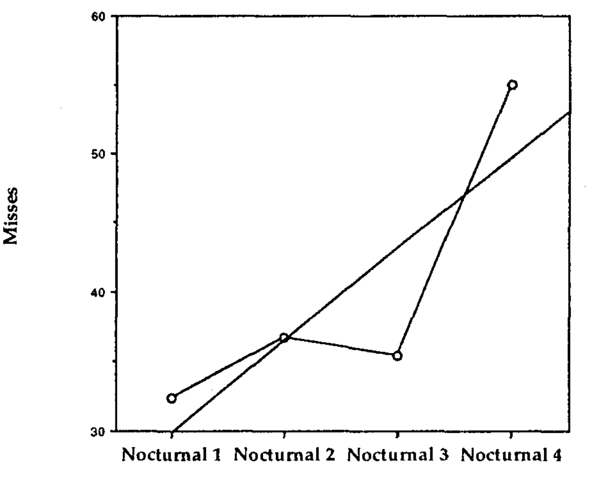

Table 2. Pearson correlations among sleep latencies on MWT and MSLT and performance on DSST, DBT, LCT.

Time: 10.30	MWT Sleep latency	MSLT Sleep latency	DSST Hits	DBT Hits	DBT Misses	DBT False positive	DBT Time	LCT Hits	LCT Misses	LCT False positive
MSLT (Sleep latency)	.53	1								
DSST (Hits)	.23	-.33	1							
DBT (Hits)	-.19	-.02	.69*	1						
DBT (Misses)	.19	.02	-.69*	-1	1					
DBT (False positive)	.40	-.45	.60	.01	-.01	1				
DBT (Time)	-.62	-.14	-.45	-	-	-.26	1			
LCT (Hits)	.23	.38	.42	.65	-.65	-.11	.10	1		
LCT (Misses)	-.23	-.38	-.42	-.65	.65	.11	-.10	-1	1	
LCT (False positive)	.02	-	.21	.16	-.16	-.03	.10	.20	-.20	1
LCT (Time)	-.85*	-.41	-.16	.29	-.29	-.31	.86*	.18	-.18	.13
Time: 23.00										
MSLT (Sleep latency)	.47									
DSST (Hits)	-.77*	-.54	1							
DBT (Hits)	-.03	.60	.15	1						
DBT (Misses)	.03	-.60	-.15	-1	1					
DBT (False positive)	.22	-.33	.21	-.35	.35	1				
DBT (Time)	.50	.50	-.56	-.09	.09	.42	1			
LCT (Hits)	-.08	.41	.30	.74*	-.74*	.28	.34	1		
LCT (Misses)	.08	-.41	-.30	-.74*	.74*	-.28	-.34	-1	1	
LCT (False positive)	-.65	-.65	.66	-.35	.35	.56	.03	.20	-.20	1
LCT (Time)	.47	.58	-.65	.05	-.05	-.15	.47	-.06	.06	-.40
Time: 1.00										
MSLT (Sleep latency)	.40									
DSST (Hits)	.35	-.39	1							
DBT (Hits)	-.11	-.47	.49	1						
DBT (Misses)	.11	.47	-.49	-1	1					
DBT (False positive)	.24	-.33	.26	.25	-.25	1				
DBT (Time)	-.20	-.12	-.51	.22	-.22	.15	1			
LCT (Hits)	.96**	.27	.30	.03	-.03	.29	-.06	1		
LCT (Misses)	-.96**	-.27	-.30	-.03	.03	-.29	.06	-1	1	
LCT (False positive)	.26	-.48	.34	.11	-.11	.79*	.30	.25	-.25	1
LCT (Time)	.03	-.25	-.27	.41	-.41	.01	.64	.30	-.30	-.02
Time: 3.00										
MSLT (Sleep latency)	.34	1								
DSST (Hits)	.19	-.47	1							
DBT (Hits)	.30	.51	-.43	1						
DBT (Misses)	-.30	-.51	.43	-1	1					
DBT (False positive)	-.78*	-.44	-.31	-.47	.47	1				
DBT (Time)	-.25	-.18	-.56	.16	-.16	.51	1			
LCT (Hits)	.94**	.21	.30	.45	-.45	-.83*	-.27	1		
LCT (Misses)	-.94**	-.21	-.30	-.45	.45	.83*	.27	-1	1	
LCT (False positive)	.45	.26	.11	.63	-.63	-.40	.14	.58	-.58	1
LCT (Time)	.10	-.30	-.25	.36	-.36	-.08	.68*	.19	-.19	.11
Time: 5.00										
MSLT (Sleep latency)	.56	1								
DSST (Hits)	-.11	-.14	1							
DBT (Hits)	.12	-.12	.53	1						
DBT (Misses)	-.12	.12	-.53	-1	1					
DBT (False positive)	-.24	-.52	-.13	.07	-.07	1				
DBT (Time)	.12	.12	-.87**	-.07	.07	.29	1			
LCT (Hits)	.71*	.19	.58	.57	-.57	-.23	-.44	1		
LCT (Misses)	-.71*	-.19	-.58	-.57	.57	.23	.44	-1	1	
LCT (False positive)	-.36	-.44	.91**	.42	-.42	.15	-.79*	.33	-.33	1
LCT (Time)	.10	-.04	-.51	.36	-.36	.02	.75*	-.09	.09	-.59

*** p< .05, ** p<.01**

DISCUSSION

Results suggest that sleepiness, alertness, and performance are differently affected by an acute night shift. The ability to maintain wakefulness is substantially spared during the night, despite the linear increasing of the readiness to fall asleep, measured by MSLT, confirming that the capacity to remain awake is not directly related to physiological sleep tendency (6,25). Naitoh and Angus (26) reviewed studies showing that subjects need 4 to 5 hr of sleep per night to maintain performance levels; instead, it is not possible to estimate the optimal amount of diurnal sleep because the sleep structure appears to be more important than the duration (27). The highest latencies recorded on both MWT and MSLT in the first nocturnal test, suggest that the brief diurnal sleep (mean TST: 190.1 mins) has a beneficial effect on the vigilance of the subjects. This effect is lasting during the night for the alertness state, in fact sleep latencies measured by means of MWT show a tendency to decrease only in the last testing session. On the contrary, the effect of previous sleep is more limited for sleep tendency that shows a significant linear increasing during the night.

The ability to carry out visuo-attentive tasks is maintained during the night, but substantial differences among tasks are observed. The performance of both DSST and DBT are not affected by increased sleepiness during the night and, thus, performance on these tasks does not show time of day effects. On the contrary, LCT is affected by sleepiness; in fact, performance shows a trend that appears to be modulated by both sleepiness and time of day variation in vigilance. Even if performance on LCT shares similar cognitive and perceptual abilities with both DBT and DSST, it seems to be more complex and monotonous and so it needs a great attentive load. Sensitivity of LCT with respect to both DBT and DSST in revealing a vigilance deterioration suggests that sleepiness due to an acute shift of the wake-sleep cycle affects only the performance required to allocate a high attentive load for a continued time.

In conclusion, results of this study confirm the multidimensional aspects of sleepiness and vigilance and suggest the need to use a multiple approach and multiple tests for the assessment of sleepiness, vigilance and performance. The dissimilar results obtained in the different physiological and behavioral tests used in this study give also useful suggestions about the possibility to single out the more adapt test for measuring specific aspects of vigilance and performance.

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PROSPECTIVE AND RETROSPECTIVE TIME ESTIMATION DURING AN ACUTE NIGHT SHIFT

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SUMMARY

Prospective and retrospective time perception of six healthy subjects was analysed during an acute shift of the sleep-wake rhythm. Aim of the study was to verify possible detrimental effects of time of the night and side effects of temazepam, taken during the day, on internal time processing, within a double-blind balanced study. Our findings show that retrospective and prospective time perception are not significantly influenced by time of the night or by temazepam intake. However, there is a trend toward significance indicating that subjects underestimate time in the pure prospective condition the night following drug assumption.

INTRODUCTION

According to Straus (1), time perception can be defined as the ego time or "erlebnisimmanente", depending on the psychological growth and development of the individual and his ability to process internal time experience.

Hart (2) has reviewed the rationale for use of estimates of time interval duration as a measure of the workload imposed by concurrent task demands. Time estimation has been often chosen for evaluation because of its acceptability to pilots, ease of implementation and scoring, and minimal learning effects. A basic distinction is drawn between two modes of time estimation: prospective and retrospective. In the prospective condition, subjects know beforehand that a temporal judgement is going to be made. In contrast, in the retrospective paradigm, subjects are asked, unexpectedly, to give an estimation of the elapsed time after they have finished the task. While in the prospective condition the subjects are motivated to monitor the time going by and allowed to attend to any available temporal cues but clocks, in the retrospective condition time estimation is incidental. The prospective and retrospective paradigms may be tested also providing an additional distracting task (e.g. count numbers or read words).

In the literature, existing discrepancies between subjective estimations and measured time are explained according to three major theoretical models: Ornstein' storage-size theory (3), Block's contextual change model (4) and the attentional allocation theory of Hicks (5) and Thomas and Weaver (6).

Ornstein's model provides that time perception depends on the storage space requested for the amount of information presented during a certain time interval. The storage space available is strictly linked to the complexity and to the organisational level of the information that is presented to the subject. In other words, major is the amount or the complexity of the information presented during a certain time interval, longer will be the estimated time (overestimation), while a well organised information will bring the subject to more accurate temporal judgements. Despite some data supporting this model (7), but also conflicting evidence (8), one of the main limits is that it is not specified what should be intended for "complexity of information" neither how the complexity itself may affect time estimation.

On the basis of Fraisse's work (9), who hypothesised that time experience is based on perceptive changes, Block (4) has proposed a time perception model based on the following postulate: if the number of individually perceived changes increases within a certain context, time estimation will increase as well. Time estimation, thus, is not based on the real number of environmental changes, but, on the subjective perception of these changes. This model is very important because it is focused on the concept of individual arousal in the time perception process, but, at the same time, it does not explain existing discrepancies between retrospective and prospective time perception.

Recently, Thomas and Weaver (6) within the frame of the attentional allocation model stressed that subjective temporal estimations are influenced from individual attention-focused strategies. If the attention is fully diverted to a certain task or the individual is facing a stressful situation, there will be a minor left capacity to process temporal intervals or to realise that contextual changes are on course. Thus, the given time estimations will be inaccurate or shorter. If the attention of the subject is focused on time processing, without any involvement of the subject in further stressful tasks, as it happens in the prospective condition, temporal estimation will be longer and more accurate. The role of attention in temporal information processing has been confirmed by Arlin (10) who found that temporal estimations were inaccurate (shorter) when the subjects were involved in difficult tasks requiring a sustained effort. By contrast less difficult tasks requiring only superficial involvement leave a greater possibility to the individual to process time information. As a consequence, time estimation will be longer and more accurate.

Following Thomas and Weaver's theory, we hypothesized that the subjects undergoing an acute shift

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of the sleep-wake rhythm, as the one we used in the Management of Operations and Rhythms for Fighting Effectiveness Optimization (M.O.R.F.E.O.) project (11), may manifest disturbances in time perception during the night while they were involved in the execution of complex tasks. We were as well interested to verify the possible side effects of a hypnotic (temazepam), a drug previously employed with success in air operations (12), on prospective and retrospective time perception, in a double blind balanced study.

MATERIALS AND METHOD

Subjects

Six healthy subjects, all males, with age ranging between 23 and 37 years (mean age 29.7 ± 5.1 years) took part to this study.

Procedure

M.O.R.F.E.O. project, a double-blind balanced study, has been described in detail elsewhere (11). Briefly, this project was planned to assess the possible detrimental effects of an hypnotic drug (temazepam), given daytime (at 02.30 P.M.) and followed by a 7.5 hours bed rest, on cognition and performance measured with different psychophysiological and cognitive probes during the same night after the ingestion of placebo or temazepam. All subjects were tested during a baseline session at 10.00 A.M. similar to those that were performed during the night.

The following time perception paradigms were analysed in both experimental conditions (Placebo or Temazepam) during a baseline (T0: 10.00 A.M.) and four night sessions (T1: 23.00-01.00, T2: 01.00-03.00, T3: 03.00-05.00, T4: 05.00-07.00):

- *Pure Retrospective Perception (PRP)* : in this condition, the subject, unaware of what is going to happen, is asked to give a time estimate of a certain temporal interval pre-established by the experimenter. A start and stop signal (auditive or visual) which is clearly recognized by the subject is provided. No additional distractor task is given.
- *Retrospective Perception with Distractor Task (PRCD)*: in this experimental condition, subject is requested to subtract sevens from a given number for a certain pre-established time interval (e.g. 65 seconds). At the end of the time period, the subject is invited to give the time estimate of the past interval, while he was involved in the arithmetical task. Also in this condition the individual is completely unaware of what will happen at the end of the counting.
- *Pure Prospective Perception (PPP)* : in this paradigm the subject knows beforehand that he will be invited to give a time estimate of a certain temporal interval which he does not know. No additional distracting task is provided.
- *Prospective Perception with Distractor Task (PPCD)*: in this paradigm the subject will give a time estimate of the temporal interval during which he has been distracted with an additional task (subtracting sevens from a given number). Subject knows beforehand that at the end of the session he will be asked a time estimate.

Pure and with distractor retrospective perception (PRP-PRCD) were tested during the baseline session (T0) and the last night session (T4: 05.00-07.00). Pure and with distractor prospective perception (PPP-PPCD) were tested in all sessions. Experimental time stimulus was ranging between 50 and 90 seconds. All the experiments were performed upon the end of Multiple Sleep Latency Test (11) administered to all subject within every baseline and night session except that for PRCD which was tested, during the last night session, upon the end of cognitive evoked potentials tests (11).

Data Analysis

All estimates given by the subjects were transformed in percent points, taking in consideration the duration of the administered stimulus (e.g. stimulus = 60 seconds: answer = 30 seconds: per cent value scored = 50). Data were elaborated by means of two-ways analysis of variance. Significant value was estabilished at $p < 0.05$, in the bidirectional hypothesis.

RESULTS

Pure Retrospective Time Perception (PRP) and with distractor (PRCD) tested at T0 (baseline) and T4 (last night session) in both experimental Conditions (Placebo and Temazepam) did not show significant variations due to Condition or Time of the night, nor any interaction of the factors (PRP x Condition: F= < 1, df= 1, not significant (ns); PRP x Time: F= 1,245, df= 1, ns; PRP x Condition x Time: F= < 1, df = 1, ns); (PRCD x Condition: F= 2,40, df= 1, ns, PRCD x Time: F= 1,600, df= 1, ns; PRCD x Condition x Time: F= < 1, df = 1, ns). Figure 1 shows means and standard deviations (SD) of PRP-PRCD, T0 and T4 of both Placebo and Temazepam Conditions.

Pure Prospective Perception (PPP) and with distractor (PPCD), tested in all Sessions (T0, T1, T2, T3, T4), did not show any statistical significance of Condition and Time of the night nor any interaction (PPP x Condition: F= 3,361, df= 1, p=0.07; PPP x Time: F= <1, df= 4, ns; PPP x Condition x Time: F=1, df= 4, ns); (PPCD x Condition: F=2,782, df= 1, ns; PPCD x Time: F= <1, df= 4, ns; PPCD x Condition x Time: F = 1, df= 4, ns). However it is important to emphasise a trend toward significance of PPP x Condition, indicating a tendency of all subjects to underestimate time in pure prospective perception (PPP) the night following Temazepam assumption. This trend, means and SD, are shown in Figure 2. Figure 3 shows means and standard deviations of PPCD of both Placebo and Temazepam Conditions.

DISCUSSION

Contrary to our expectations this study yelded negative results. We could not demonstrate any disturbance in prospective and retrospective time perception during the night, while the subjects were performing complex and "activating" tasks, as those planned for M.O.R.F.E.O. project. Further, temazepam taken daytime at 02.30 P.M. and followed by a 7.5 hours bed rest, did not affect

retrospective and prospective with distractor task time perception during the night, although a statistical trend toward significance would indicate that subjects underestimate time in the pure prospective paradigm during Temazepam Condition.

Despite some methodological dissimilarities, Roth and coll. in 1979 (13) published a double-blind study exploring the link between time perception and hypnotic drugs (flurazepam, temazepam and quinalbarbitone). This work, although few methodological flaws in the assessment of time perception, demonstrated a "time of the day" effect of temporal judgements. According to these authors, healthy subjects show a tendency to underestimate time in the evening hours, 22.5 hours after placebo or drug administered before night sleep, while no disturbance of time estimation was found 3.5 (night) and 10 hours (early morning) after the administration of any substance. On the contrary, our findings would indicate that there might be some effect of temazepam in affecting prospective time perception. Some support to this hypothesis comes from correlational data of M.O.R.F.E.O. project (not presented in this study) indicating that a poor prospective time perception performance in the first three night sessions (11.00 P.M.-01.00. A.M., 01.00 A.M.-03.00 A.M., 03.00 A.M.-05.00 A.M.) is related to a minor amount of slow wave sleep (S4) scored within Temazepam Condition. This association is evident only in the third night session (03.00 A.M.-05.00 A.M.) when Placebo was administered. This finding, although preliminary, would suggest that, following temazepam administration, performance failure of prospective time perception paradigm is evidenced earlier during the night.

There are some limits of this study that may have affected the possibility to detect significant changes in time perception during the night. Firstly, the small number of the subjects may not be sufficient to evidence significant changes. Secondly, retrospective time estimation, in consideration of the "surprise" paradigm used (see materials and method section for details), was not tested in all night session, but only in the last one. This caveat is important because we may have lost some night effects of retrospective time perception paradigm. Thirdly, in our sample, the variability between subjects in the assessment of time perception was high (see standard deviations of measured variables in the Figures), confirming that time perception is highly influenced by multiple subjective variables such as personality or speed of information processing (14, 15) and, thus, difficult to assess.

In conclusion, retrospective and prospective time perception, as tested within M.O.R.F.E.O. project, is not influenced to a significant level from night hours nor from temazepam. However, we found a trend toward significance indicating that subjects underestimate time in the PPP paradigm after Temazepam intake. Further studies are clearly needed to clarify possible detrimental effects of hypnotic drugs on time perception performance.

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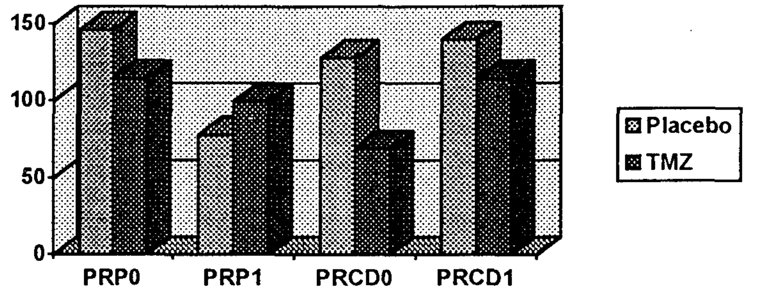
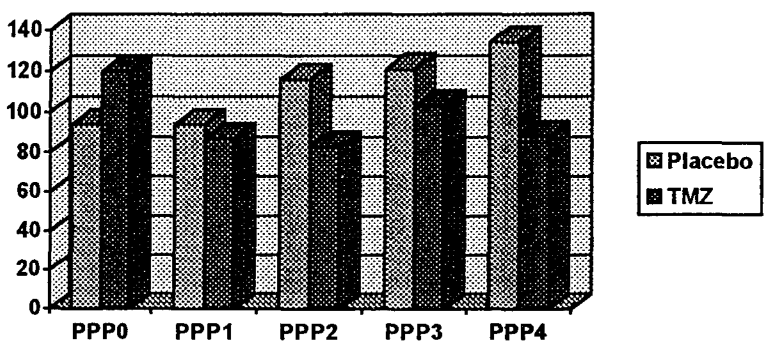
Figure 1
Pure and with Distractor Retrospective Perception (PRP-PRCD)



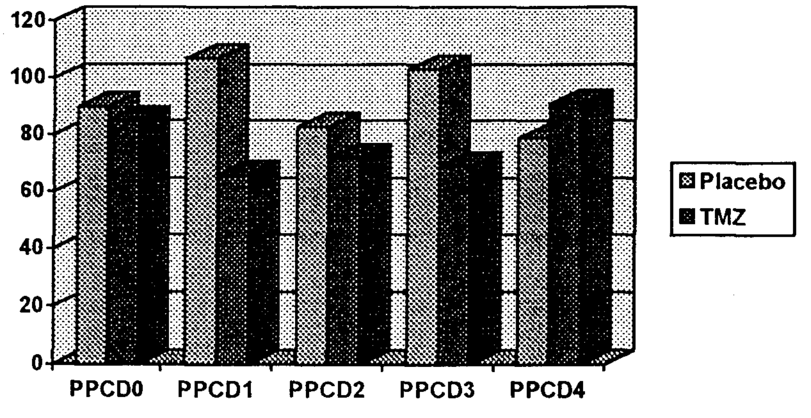
legend: prp 0,1, prcd 0,1 = t 0 and t 4; TMZ = temazepam; **Placebo**: prp 0 = 146 ± 155, prp 1 = 77,5± 32, prcd 0 = 128 ± 67, prcd 1 = 140 ± 60;
TMZ : prp 0 = 115 ± 62, prp 1 = 100 ± 68, prcd 0 = 69 ± 45, prcd 1 = 115 ± 50;

Figure 2
Pure Prospective Perception (PPP)



legend: pp p 0...4 = t 0...t 4; TMZ = temazepam; **Placebo**: ppp 0 = 94 ± 24, ppp 1 = 94 ± 24, ppp 2 = 116 ± 38, ppp 3 = 121 ± 83, ppp 4 = 134 ± 70;
TMZ : ppp 0 = 120 ± 46, ppp 1 = 87 ± 21, ppp 2 = 83 ± 17, ppp 3 = 103 ± 17, ppp 4 = 88 ± 21;

Figure 3
Prospective Perception with Distractor (PPCD)



legend: ppcd 0...4 = t 0...t 4; TMZ = temazepam; **Placebo**: ppcd 0 = 90 ± 48, ppcd 1 = 107 ± 46, ppcd 2 = 83 ± 15, ppcd 3 = 103 ± 28, ppcd 4 = 79 ± 34;
TMZ : ppcd 0 = 85 ± 51, ppcd 1 = 66 ± 39, ppcd 2 = 72 ± 37, ppcd 3 = 69 ± 33, ppcd 4 = 91 ± 25;

LA FATIGUE EN AERONAUTIQUE - LES BASES D'UN MODELE -

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RESUME

Bien que très souvent utilisée dans le langage courant, la fatigue demeure un concept mal défini sur le plan scientifique. L'absence d'une définition claire reste liée au fait que la fatigue revêt de multiples aspects, se rapportant à des manifestations physiologiques, sensorielles ou mentales. La fatigue physique et la fatigue sensorielle demeurent actuellement les mieux connues et l'on dispose d'indicateurs capables de les évaluer. La fatigue mentale reste pour l'instant un concept subjectif, suggéré par analogie avec la fatigue physique et sensorielle. Elle se caractérise par une diminution du rendement de l'opérateur qui se traduit pour lui par la nécessité de fournir un effort plus important pour maintenir ses performances à un niveau équivalent. Par ailleurs, les mécanismes d'accumulation et de récupération de la fatigue demeurent peu explorés, alors que leur connaissance se révèle essentielle, notamment pour formuler des recommandations concernant les temps de missions et de repos des équipages. A partir des données disponibles dans la littérature et des connaissances actuelles, une ébauche de modèle d'étude applicable en aéronautique est proposée. Ce modèle prend notamment en compte différentes composantes, dont les conditions d'environnement, les rythmes circadiens et la nature de la tâche. Il est destiné à servir de support à des expérimentations menées en laboratoire et en situations réelles.

1 - INTRODUCTION -

En aéronautique civile ou militaire, la fatigue constitue une limitation essentielle pour les équipages, tant pour des vols courts que long-courriers. Bien que très souvent utilisée dans le langage courant, la notion de fatigue reste vague sur le plan scientifique comme l'illustrent les nombreuses définitions qui lui sont associées. En 1947, Bartley et Chute en dénombraient déjà plus de 100. On peut considérer que ces multiples définitions conduisent paradoxalement à une absence de définition. Souvent assimilée à des notions telles que le besoin de sommeil, la somnolence ou l'hypovigilance, la fatigue revêt pourtant d'autres formes dont les manifestations se révèlent plus subtiles. La fatigue constitue donc un concept très large, englobant beaucoup d'aspects du fonctionnement humain.

Cet article présente une revue de travaux ayant porté sur certains des mécanismes susceptibles de générer de la fatigue ainsi que sur ses diverses manifestations. Ce travail d'analyse bibliographique vise dans un premier temps à permettre une clarification du concept de fatigue en prenant en compte ses diverses composantes. A partir de la revue bibliographique, les premières bases d'un modèle sont ensuite présentées. Ce modèle doit servir de support à des investigations destinées à mieux appréhender les phénomènes de fatigue en aéronautique. A terme, l'objectif est de pouvoir utiliser le modèle établi afin de prédire chez des pilotes à la fois l'apparition d'un état de fatigue et, éventuellement, le temps nécessaire à sa récupération.

2 - CARACTERISATION DES ETATS DE FATIGUE -

2.1. Définitions -

Malgré la multitude des définitions proposées, la plupart des auteurs s'accordent pour définir la fatigue comme un ensemble de manifestations engendrées par une activité intense et/ou prolongée. Ces manifestations s'accompagnent, sur le plan subjectif, d'une "sensation de fatigue" et, sur le plan objectif, d'une diminution du rendement en terme de performance (plus d'informations nécessaires en entrée pour exécuter une même tâche ou une baisse de l'efficacité pour une même quantité d'informations traitées). Ces manifestations se révèlent généralement réversibles, c'est-à-dire qu'elles cessent sous l'effet du repos ou du sommeil. Cette définition, peut s'appliquer à tous les aspects du fonctionnement de l'opérateur humain, tant sur le plan moteur, sensoriel ou cognitif. Elle repose sur trois notions :

- l'effort,
- les manifestations de la fatigue,
- la récupération.

En fait, de l'analyse de la littérature, on peut distinguer deux conceptions très différentes pour tenter de décrire les origines de la fatigue. L'une privilégie l'intensité de l'effort, l'autre la durée de l'effort.

2.2. Fatigue et intensité de l'effort -

La plupart des théories de la fatigue se rapportant à cette conception reposent sur un aspect "énergétique". L'effort fourni dans le travail consomme une partie de "l'énergie" disponible. C'est cette consommation d'énergie qui conduirait à un état de fatigue (Lee et coll., 1991).

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Schmidtke (1969) insiste sur la sollicitation émanant de la tâche réalisée. Selon cet auteur "la fatigue se présenterait comme un phénomène consécutif à une sollicitation préalable ; elle a pour effet une diminution réversible des performances et une dégradation transitoire des fonctions ; elle s'accompagne d'une diminution de la satisfaction dans le travail et d'une augmentation de la sensation d'effort". A cette définition est associée une classification des états de fatigue :

- dans sa forme initiale, les premiers signes correspondent à des troubles bénins de la zone fonctionnelle intéressée par l'activité,
- une forme plus avancée s'installe quand les troubles deviennent conscients (phase homéostasique). A ce moment, des fluctuations de rendement apparaissent et peuvent s'interpréter comme une tendance des sujets à compenser une diminution de l'efficience par une stimulation de la volonté (auto-activation),
- survient ensuite une phase dans laquelle la performance présente une nette tendance régressive. On y trouve des troubles affectant plusieurs fonctions, ce qui signifie un déroulement perturbé des processus centraux. Cette phase serait caractéristique d'une fatigue globale,
- si l'activité n'est pas interrompue au cours de la phase précédente, on observe des troubles plus profonds de l'équilibre fonctionnel qui se traduisent au niveau comportemental par des modifications de la personnalité et qui présentent de nombreuses similitudes avec certains syndromes psychopathologiques tels que l'asthénie.

2.3. Fatigue et durée de l'effort -

Pour cette seconde approche, la fatigue résulterait d'une diminution temporaire des capacités de travail après une longue exposition à un effort (Cameron, 1973 ; Sperandio, 1984 ; Ono et coll., 1991). Ainsi, le déclin des capacités de travail se manifesterait par une perturbation de l'état de différentes fonctions du corps qui entraînerait une baisse d'efficience et de la qualité du travail, avec une relation moins favorable entre le rendement et l'effort nécessaire à son accomplissement. En d'autres termes, pour maintenir une performance équivalente, le sujet fatigué doit fournir un effort plus important. Par ailleurs, on peut considérer que cette augmentation de l'effort agit en augmentant le niveau de fatigue, ce qui se traduit par une accumulation de fatigue.

Elias et Audran (1978) corroborent cette hypothèse reposant sur la durée d'exposition à l'effort en définissant la fatigue comme "une réponse généralisée à des situations de travail difficiles au cours d'une période prolongée, avec des effets qui pourraient être aigus ou chroniques. La fatigue apparaît comme la manifestation d'un état critique du système qui devra restructurer l'ensemble des variables comportementales vers la récupération." Dans cette définition, une fonction adaptative de la fatigue est suggérée. Ses manifestations constitueraient un signal d'alarme pour l'organisme, l'incitant à cesser l'activité.

2.4. Quelle approche ? -

En résumé, la durée et l'intensité de l'effort constitueraient les deux principaux facteurs identifiés comme causes de la fatigue. On peut se demander si ces deux facteurs ne traduisent pas des différences à la fois dans les manifestations de la fatigue et dans les processus de récupération associés. Cette question reste pour l'instant sans réponse. Elle constitue plus une hypothèse de travail qu'il conviendra d'évaluer au cours des futures investigations. Par contre, il paraît bien établi qu'une tâche très longue et très intense peut conduire à un état d'épuisement (Bodrov, 1988).

3 - LES MANIFESTATIONS DE LA FATIGUE -

Traditionnellement, les manifestations de la fatigue sont classées selon la zone fonctionnelle sollicitée par l'activité. Ainsi, on distingue la fatigue musculaire qui peut survenir lors d'un travail physique et la fatigue sensorielle qui va apparaître à la suite d'une sollicitation plus ou moins intense et/ou prolongée des organes sensoriels. Pour d'autres auteurs, les manifestations de la fatigue ne restent pas spécifiques d'une fonction : elles doivent plutôt être classées par rapport à l'intensité de la fatigue et correspondent alors à un état général de l'organisme. On se place alors dans un concept de "fatigue générale".

3.1. Les manifestations spécifiques -

3.1.1. Fatigue musculaire -

Chronologiquement, la fatigue musculaire a été la première à faire l'objet de recherches, notamment en raison de ses implications dans le travail manuel (Scherrer, 1967). Bien qu'il reste encore des inconnues sur les mécanismes impliqués, les phénomènes de fatigue musculaire paraissent assez bien connus. On distingue généralement deux types de fatigue musculaire en fonction de la nature de l'effort demandé : une fatigue associée à un effort soutenu et une fatigue liée au maintien d'une même posture sur des périodes prolongées. Un travail musculaire intense se traduit par une diminution des performances musculaires, une diminution du rythme contraction-relaxation et un allongement du temps entre la stimulation et le début de la contraction (Grandjean, 1983). Dans le contexte aéronautique dans lequel se situe ce travail, la fatigue posturale présente le plus d'intérêt. Celle-ci se trouve notamment accentuée lors du travail de précision et du travail sur écran qui nécessitent un positionnement très précis de la tête (Verriest, 1985) et qui entraînent une dépense musculaire bien supérieure au port normal de la tête. Cette rigidification augmente la valeur des contraintes exercées sur la colonne cervicale. Compte tenu de la prépondérance de plus en plus marquée des écrans cathodiques dans les avions de nouvelle génération, cette composante de la fatigue mérite d'être très sérieusement étudiée.

3.1.2. Fatigue sensorielle -

Depuis une vingtaine d'années, la fatigue sensorielle a fait l'objet de nombreux travaux et en particulier la fatigue visuelle là encore en raison du développement du travail sur écran. Avec la centralisation des informations sur des écrans, il s'agit d'un aspect à ne pas négliger. La fatigue visuelle, liée à une sollicitation excessive de l'oeil se traduit par des symptômes polymorphes : des signes oculaires fonctionnels (picotements, irritations, éblouissements), physiques (douleurs, rougeurs,...) et généraux (céphalées, vertiges, insomnie,...) (Berthemy Pellet, 1991).

La fatigue auditive constitue également un important champ d'investigations, afin de déterminer à la fois ses origines et ses manifestations. Sur le plan de l'origine, certains auteurs ont émis l'hypothèse que l'organe récepteur (la cochlée) ne constitue pas le seul lieu où la fatigue s'exerce. Une composante centrale, c'est-à-dire au niveau des centres auditifs du système nerveux est notamment évoquée (Klein et Mills, 1981 ; Sorin et Thouin-Daniel, 1983). Cette composante expliquerait qu'une exposition au bruit réduise les performances mentales d'un sujet. Outre les dégradations purement sensorielles sur le plan du seuil auditif et de la perception de certaines fréquences (Feth et coll., 1979), on constate une réduction de la compréhension de la parole. Comme pour la fatigue visuelle, cet aspect mérite une attention particulière dans le domaine aéronautique, en raison de l'importance des communications à l'intérieur des cockpits et vers l'extérieur (contrôle aérien).

3.1.3. Fatigue mentale -

Par analogie avec les concepts de fatigue musculaire et de fatigue sensorielle, le concept de fatigue mentale a émergé au cours des vingt dernières années pour désigner les dégradations des fonctions mentales consécutives à un travail intellectuel. Dans le domaine aéronautique, cette notion présente un intérêt capital dans la mesure où les tâches de pilotage requièrent des raisonnements complexes dans des temps limités. Ce concept, étroitement lié à celui de charge mentale, a été maintes fois critiqué. Pour Sperandio (1984) "à l'imprécision du terme *fatigue* on ajoute celle de l'adjectif *mentale*". En fait, il n'existe pas à ce jour de preuves expérimentales que le traitement cognitif de l'information produise un état de fatigue. On constate parfois une diminution des performances à la suite d'un effort mental intense. Cette dégradation n'est pas toujours constatée en raison de la difficulté à isoler les différentes étapes du traitement de l'information. Puisque tout traitement de l'information et les réponses qu'il implique mettent en jeu une activité sensorielle et musculaire, il paraît difficile de pouvoir mettre en évidence une fatigue mentale "pure". A ce titre, les travaux mentionnés dans le domaine de la fatigue auditive montrent qu'une sollicitation sensorielle peut conduire à elle seule, à une diminution des performances mentales. Si l'on ne dispose pas de preuves objectives de l'existence de cette fatigue mentale, il n'en demeure pas moins que des manifestations subjectives existent et qu'il convient de les prendre en compte.

3.2. La fatigue générale -

Aux formes spécifiques de la fatigue, d'autres auteurs substituent la notion de "fatigue générale" qui désigne des sensations pour lesquelles aucune manifestation particulière et localisée ne peut être isolée. Cette conception émane principalement des auteurs russes (Platonov, 1970 ; Medvedev et Mar'yanovich, 1983). Bodrov (1988), dans le domaine aéronautique, classe les manifestations de la fatigue en fonction de leurs intensités :

- la fatigue compensable est essentiellement caractérisée par des dégradations des sensations subjectives qui surviennent principalement à la fin du vol. Elle disparaît après une nuit de repos,
- la fatigue aiguë se caractérise par une certaine inertie et une apathie s'accompagnant parfois de difficultés d'endormissement,
- la fatigue chronique s'installe après une exposition répétée à un travail intensif. Elle se traduit par des sensations de fatigue tout au long du vol, une faiblesse et une inertie générale, une apathie, des bourdonnements, des maux de tête, un manque d'appétit, des difficultés d'endormissement et des éveils fréquents. La récupération ne s'effectue qu'après une longue période de repos,
- enfin, l'épuisement (*burnout* en anglais) se caractérise par des sensations de fatigue qui persistent plusieurs jours même en l'absence de travail. Le sujet présente une apathie, des maux de tête persistants, une perte de l'appétit, des vertiges, des nausées et parfois des vomissements, des cardialgies, une augmentation de la fréquence cardiaque au repos, des membres engourdis et une irritabilité. On constate également des troubles du sommeil : sommeil peu profond, éveils fréquents, cauchemars et insomnies. Ces troubles s'accompagnent d'une somnolence diurne. La récupération n'est généralement obtenue qu'à l'aide d'un traitement thérapeutique. Cette symptomatologie peut être assimilée à celle décrite par Bugard en 1960, lorsqu'il décrit un syndrome général d'inadaptation. Ce concept a fait l'objet de nombreux travaux, essentiellement dans le domaine du stress (pour une revue, voir Neveu, 1995). Cette réaction de l'organisme est considérée comme une réaction inadaptée, un stress négatif par opposition au stress positif (Selye, 1979). Cette notion fait intervenir d'autres composantes que l'effort, comme la satisfaction dans le travail et les évéments de vie (biographie).

On peut noter que ces symptômes se révèlent assez peu spécifiques. Par ailleurs, ils s'inscrivent sur un continuum des différents états de fatigue. Chaque état se traduit par l'apparition de nouveaux symptômes. Ceux constatés dans les formes légères (fatigue compensable) se retrouvent également dans les formes

plus sévères (épuisement), mais avec une intensité beaucoup plus élevée. La récupération de ces symptômes s'inscrit sur ce continuum puisque ceux-ci persistent d'autant plus que le niveau de fatigue est élevé, même lorsque le sujet cesse son activité.

3.3. Fatigue spécifique ou générale ? -

Au total, les données de la littérature présentent une apparente contradiction. Certains auteurs considèrent la fatigue comme le résultat d'un effort localisé (musculaire, sensoriel,...), d'autres l'appréhendent comme un phénomène global, avec des manifestations plus généralisées dont la sévérité augmente avec le niveau de fatigue. En l'état actuel des connaissances, il ne semble pas pertinent de privilégier l'une ou l'autre des conceptions mais plutôt de tenter de les intégrer dans le développement d'un modèle de la fatigue en tentant de tenir compte de leur complémentarité.

4 - INDICATEURS DE LA FATIGUE -

Etablir une liste exhaustive des indicateurs de la fatigue comporte les mêmes difficultés que de proposer une définition du concept lui-même. On peut néanmoins citer les paramètres les plus utilisés.

Certains de ces indicateurs apparaissent spécifiques d'une zone fonctionnelle. L'électromyographie (EMG) constitue par exemple un marqueur de la fatigue localisée au niveau des muscles. Néanmoins, il est intéressant de remarquer que des signes localisés de même nature peuvent apparaître dans le cas de fatigue générale (Bodrov, 1988). Ainsi, cet auteur constate chez des pilotes présentant des symptômes de fatigue chronique, une réduction de la force et de l'endurance musculaire alors que ces pilotes n'ont pas été exposés à une charge physique particulière.

D'autres indicateurs traduisent davantage une fatigue globale, non spécifique. C'est le cas notamment de l'électrocardiogramme (ECG), de la fréquence respiratoire et de la pression artérielle. De même, certains indicateurs biochimiques sont souvent utilisés comme marqueurs de la fatigue. Lors d'un état d'épuisement, on note par exemple dans le plasma une diminution du nombre des plaquettes, une diminution de la concentration de l'hémoglobine. Par ailleurs, le taux de cortisol présente une augmentation dans les situations de surcharge mentale. Dans les urines, une augmentation des catécholamines, de la créatine et des protéines est généralement constatée.

On peut considérer que d'autres indicateurs neurophysiologiques, comme l'électro-encéphalogramme (EEG), constituent également des mesures indirectes d'états de fatigue. En effet l'EEG, qui apporte une évaluation directe du niveau d'activation, renseigne indirectement sur un niveau de fatigue. La somnolence peut refléter une privation de sommeil ou un sommeil de mauvaise qualité qui constituent des symptômes de fatigue souvent évoqués chez les personnels affectés à des postes en horaires décalés ou en travail posté. D'autre part, on peut considérer que la diminution du niveau d'éveil, lorsqu'elle survient de manière incontrôlée au cours de l'activité, constitue un état contre lequel le sujet est amené à lutter, à fournir un effort. Cette "auto-activation" peut constituer une source de fatigue supplémentaire pour ce dernier.

Les potentiels évoqués tardifs, qui évaluent classiquement les processus attentionnels ainsi que la charge de travail, peuvent également refléter, dans une certaine mesure, des manifestations de la fatigue en cas de surcharge de travail.

Les composantes subjectives de la fatigue sont quant à elles évaluées par l'intermédiaire de questionnaires ou d'échelles analogiques. On demande au sujet d'évaluer sa sensation de fatigue en inscrivant une marque sur une ligne horizontale séparant deux adjectifs opposés (par exemple : fatigué-reposé).

Par ailleurs, la dimension affective de l'opérateur doit être prise en considération. Il existe divers outils permettant d'apprécier cette composante, notamment au travers de questionnaires biographiques tels que ceux développés par Crocq et Bugard (Crocq, 1993 ; Bugard, 1960). Ces échelles dites d'événements de vie permettent d'appréhender la composante affective souvent évoquée pour contribuer à accroître les manifestations de la fatigue.

5 - LA FATIGUE EN AERONAUTIQUE -

5.1. Principales causes -

En s'appuyant sur le concept de fatigue générale, Platonov (1960), repris par Bodrov (1988), distingue, trois types de facteurs intervenant dans la fatigue en aéronautique :

- <u>des facteurs principaux</u> liés à une charge intense et/ou prolongée au cours de vols courts ou long-courriers. Cette charge se trouve essentiellement déterminée par une activité cognitive, tantôt excessive, tantôt réduite, par une complexité de la tâche, la responsabilité incombant aux pilotes, la pression temporelle ainsi que par la proportion élevée d'activités non directement liées au vol. Une charge physique peut être également évoquée liée au maintien de la posture,
- <u>les facteurs d'environnement du vol</u> : la durée, le nombre de décollages et de périodes de travail dans un cycle de 24 heures, la durée totale de vols dans la journée, la semaine, le mois ou l'année,
- <u>les facteurs additionnels</u> qui accentuent les manifestations de la fatigue : des conditions de vol défavorables, le stress et les activités mentales excessives avant le vol.

D'autres facteurs interviennent qui prédisposent le pilote à la fatigue. C'est le cas notamment des perturbations du repos, des horaires de repas et de

longues interruptions entre les vols. Les variables individuelles telles que l'âge, les états pathologiques et la personnalité peuvent également influencer de manière très importante les états de fatigue.

5.2. Le cas des vols long-courriers -

Dans le contexte aéronautique, les vols long-courriers occupent une place particulière dans la mesure où plusieurs facteurs sont associés. En effet, les équipages, notamment dans les avions modernes, se trouvent confrontés à la fois à des durées de travail élevées et à des privations partielles ou totales de sommeil lors des vols de nuit. A ces facteurs, s'ajoute très souvent une désynchronisation des rythmes biologiques liée aux décalages horaires (Wegmann et coll., 1986 ; Nicholson et coll., 1986). Par ailleurs, la charge de travail présente des variations importantes au cours du vol. Elevée, voire très élevée dans les phases critiques, elle devient très réduite dans les phases de croisière, entraînant une situation de monotonie (Graeber, 1990). L'ensemble de ces facteurs concourent donc à dégrader le niveau d'éveil de l'équipage. Les travaux que nous avons menés en situation réelle (Coblentz et coll., 1991 ; Cabon et coll., 1993) ont permis de développer des solutions pratiques et applicables par les équipages afin de limiter les baisses de vigilance pendant le vol et de préserver les sommeils des équipages pendant la rotation.

Au cours de ces travaux, il a été constaté des taux élevés d'hypovigilance, détectés à partir d'une augmentation significative dans la bande alpha de l'EEG et une augmentation des clignements oculaires. Ces baisses du niveau d'éveil surviennent le plus fréquemment lors de la croisière et parfois simultanément pour les deux pilotes, même lors de vols en équipage à deux. Ces résultats ont pu être mis en relation avec le contexte du vol (durée, destination, composition de l'équipage), avec les activités au cours du vol (communications, tâches, prise des repas,...) et les durées de sommeil avant la rotation, en vol (équipages renforcés) et à l'escale. Les recommandations qui ont été élaborées puis testées sur des vols réels (Mollard et coll., 1995 ; Coblentz et coll., 1993 ; Cabon et coll., 1995) reposent sur une gestion optimisée des repos ainsi qu'une alternance de phases de veille active-veille passive qui permet à la fois d'induire une rupture dans la monotonie du vol et de procurer, lors des vols de nuit, des périodes de repos dans le cockpit, successivement pour chaque pilote. Des recommandations spécifiques sont également proposées aux pilotes afin de les aider à lutter contre les effets du décalage horaire. Une exposition à la lumière dans des plages horaires appropriées permet notamment d'accélérer le processus d'ajustement des rythmes biologiques à l'horaire local. L'ensemble de ces recommandations s'est avéré très efficace et a permis de réduire significativement les taux d'hypovigilance en vol. Cette amélioration peut être attribuée essentiellement à une meilleure gestion du sommeil et à une réduction de la monotonie. Ces travaux ont abouti à la réalisation d'un guide de recommandations à l'usage des équipages (LAA-DGAC, 1995).

Au cours de cette recherche, nous avons été amenés à travailler sur des vols de certification de l'Airbus A340 (Coblentz et coll., 1993) dont le contexte peut être assimilé à une activité à la fois longue et prolongée. Cette recherche a été conduite en collaboration avec l'équipe de H.M. Wegmann (DLR Institute für Flugmedizin) qui a conduit des investigations concernant le sommeil, les sensations de fatigue, la charge de travail et le stress (Wegmann et coll., 1993). Ces vols long-courriers, de durées supérieures à 10 heures, présentaient la particularité d'être effectués en équipage à deux avec des scénarios de pannes déclenchés de manière aléatoire. Ces conditions étaient donc susceptibles de créer un état de fatigue tel qu'il a été défini plus haut. Les figures n° 1 et 2 présentent les pourcentages d'hypovigilance calculés pendant les phases de montée, de descente et toutes les heures au cours de la phase de croisière lors d'un vol Paris-San Francisco et San Francisco-Paris. On constate, pour le vol aller, une augmentation très importante du taux d'hypovigilance au bout de 7 heures de croisière pour le commandant de bord (CM1) et de 9 heures de croisière pour le copilote (CM2). Les taux redeviennent nuls au cours de la phase de descente. Ce résultat peut être interprété comme un état de fatigue s'installant progressivement au cours du vol avec un maximum en fin de vol. Lors du retour, on note, pour le copilote, une première augmentation du pourcentage d'hypovigilance en début de croisière, puis une seconde après 8 heures. Pour le commandant de bord, le taux n'augmente que légèrement en fin de vol. Les résultats se révèlent donc assez similaires à ceux obtenus lors du vol aller. L'augmentation précoce du taux d'hypovigilance du copilote est probablement liée à la privation de sommeil qui a été constatée à l'escale (Wegmann et coll., 1993). Par ailleurs, il a été constaté en fin de vol, une augmentation concomitante de l'évaluation subjective de la charge de travail, des sensations de fatigue et du taux de cortisol. Ces manifestations peuvent être assimilées à un état de fatigue aiguë, telle que décrite par Bodrov (1988).

Ces résultats suggèrent donc qu'une fatigue liée à un effort prolongé et intense peut conduire à des manifestations de fatigue caractérisées par une réduction du niveau d'éveil. Cette réduction du niveau d'éveil peut être elle-même considérée comme une source d'effort pour le pilote. En effet un niveau d'éveil minimum étant requis pour effectuer la tâche, il est amené à mobiliser des ressources pour maintenir un éveil suffisant. On peut émettre l'hypothèse que les taux élevés de cortisol et les sensations de fatigue apparaissant à la fin du vol traduisent cet état interne des pilotes. Bien que les résultats présentés ne portent que sur une rotation, ils illustrent bien une manifestation de la fatigue liée au contexte du vol : longue période de travail et survenue de pannes.

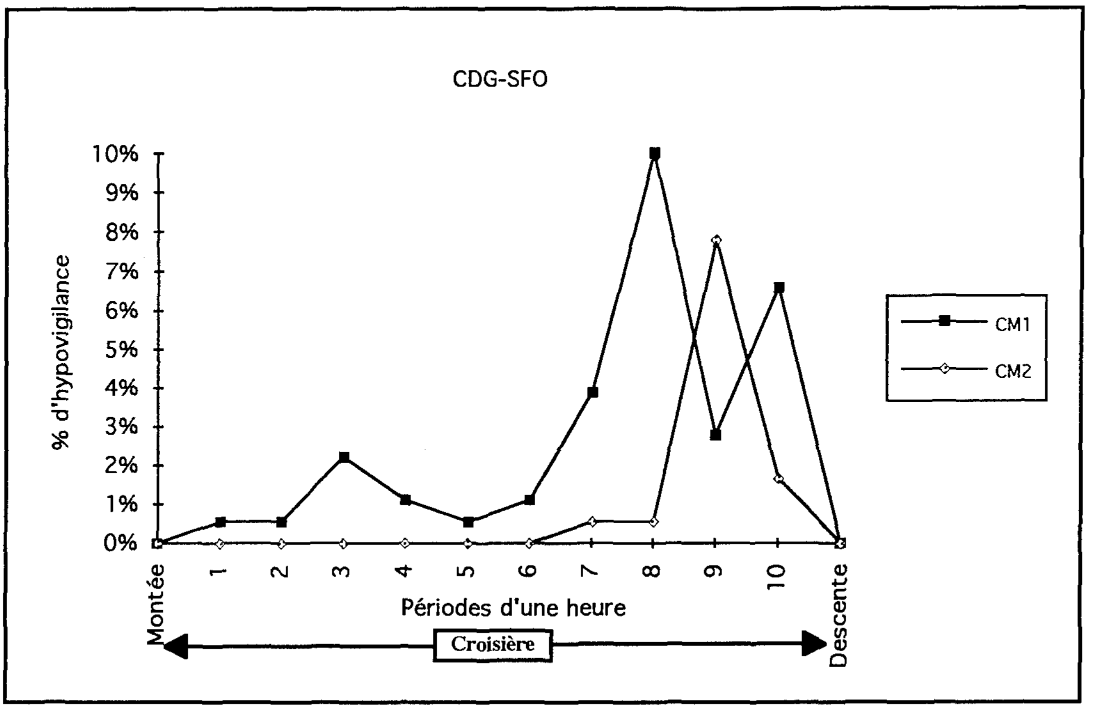

Figure n°1. Pourcentage d'hypovigilance lors de la montée, la descente et par périodes d'une heure au cours de la croisière pour le commandant de bord (CM1) et le copilote (CM2).
Vol de certification de l'Airbus A340.
Vol de jour Paris (CDG)-San Francisco (SFO).
Durée de sommeil avant le vol :
• CM1 : 7 heures
• CM2 : 8 heures

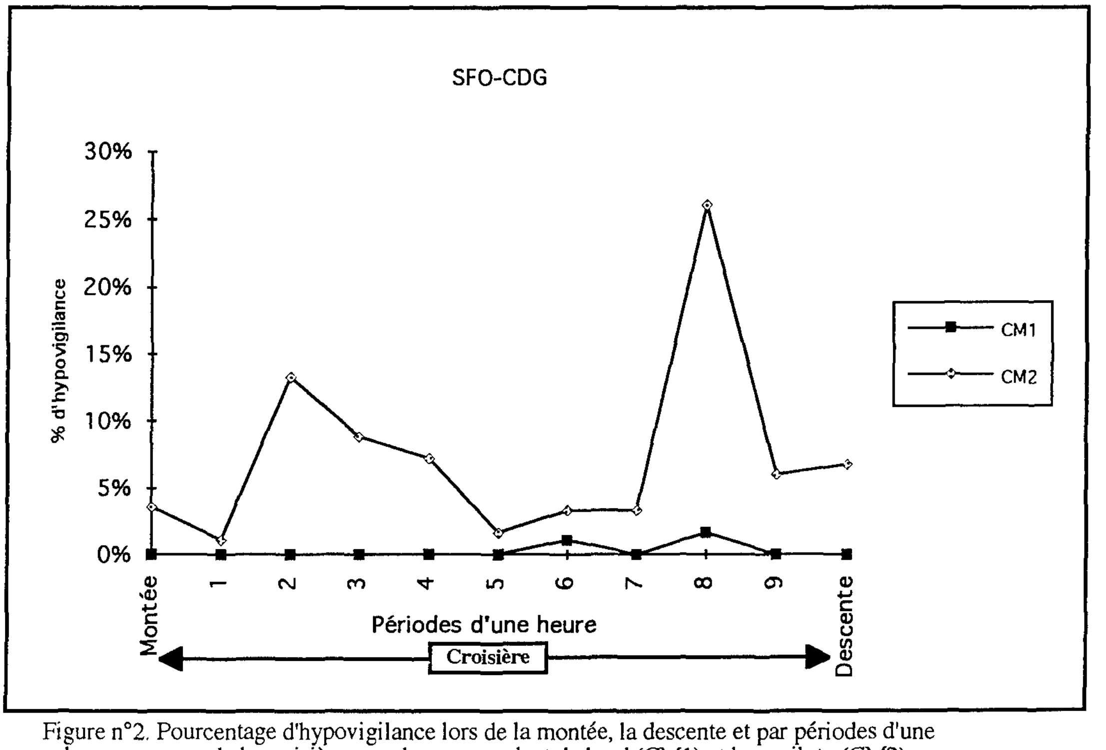

Figure n°2. Pourcentage d'hypovigilance lors de la montée, la descente et par périodes d'une heure au cours de la croisière pour le commandant de bord (CM1) et le copilote (CM2).
Vol de certification de l'Airbus A340.
Vol de nuit San Francisco (SFO)-Paris (CDG).
Durée de l'escale à San Francisco : 24 heures
Durée de sommeil avant le vol :
• CM1 : 9 heures
• CM2 : 4 heures 30

6 - VERS UN MODELE GLOBAL DE LA FATIGUE...

L'analyse de la littérature ainsi que les premiers résultats présentés posent la question de la notion de fatigue. Recouvre-t-elle des manifestations indépendantes, spécifiques, localisées à une zone fonctionnelle ou bien représente-t-elle une manifestation beaucoup plus globale ? Bien qu'il ne soit pas possible, dans l'état actuel des connaissances, d'apporter une réponse définitive, des orientations émergent d'ores et déjà. Ces orientations permettent de poser les premières bases d'un modèle applicable à l'aéronautique (figure n°3).

Ce premier modèle intègre à la fois les dimensions physiologiques et psychologiques de l'opérateur. Les causes de la fatigue, identifiées comme externes à l'opérateur sont potentialisées par les caractéristiques internes de l'opérateur (rythmes biologiques, niveau d'éveil, personnalité, pathologies,...). L'ensemble de ces facteurs se traduit, chez l'opérateur, par une consommation d'énergie, un effort, directement responsable des états de fatigue. Dans ce modèle, la fatigue est considérée comme un état général de l'opérateur se manifestant par des signes plus spécifiques sur le plan physiologique, musculaire, sensoriel, cognitif... Cet état général s'inscrit sur un continuum allant de la fatigue compensable à l'épuisement. A l'exception de l'état d'épuisement, la cessation de l'activité se traduit par un processus de récupération et une diminution plus ou moins lente des symptômes. L'épuisement entraîne, au contraire une persistance de ces signes, même lorsque l'activité a cessé. Lorsque l'activité se poursuit alors que le sujet est déjà fatigué, la fatigue devient elle-même une source d'effort (la performance requise devient plus difficile à atteindre, le rendement diminue) susceptible d'accroître le niveau de fatigue. D'une fatigue compensable ou aiguë, on tend alors vers une fatigue chronique, voire vers l'épuisement. Dans une certaine mesure, ceci peut rendre compte de ce qui est couramment appelé une "accumulation de fatigue" au cours des mois ou de l'année.

7 - CONCLUSIONS - PERSPECTIVES -

Le modèle présenté dans cet article constitue une première approche qui permet d'intégrer à la fois les causes de la fatigue, les facteurs individuels, les manifestations de la fatigue ainsi que les processus de récupération. Ce modèle présente deux intérêts majeurs. Le premier est qu'il permet de clarifier la notion de fatigue à la fois dans ses manifestations globales et spécifiques. Le second est qu'il ouvre des perspectives de recherche. L'objectif général de ces investigations consiste à valider et à enrichir le modèle et à pouvoir développer des contremesures efficaces dans le domaine aéronautique. Quatre grands axes de recherche complémentaires sont envisagés.

Le premier axe vise à mieux cerner la perception des phénomènes de fatigue par les équipages. Cette approche va reposer sur l'utilisation de questionnaires et d'entretiens dans le but de déterminer et de classer les vols générant de la fatigue.

Le deuxième concerne une analyse détaillée des rapports d'incidents et d'accidents d'avions pour lesquels la fatigue a pu jouer un rôle, même si elle n'a pas été considérée comme la cause primaire. Cette analyse devrait permettre d'identifier d'éventuels facteurs communs dans les circonstances qui entourent ces accidents. De la même manière, l'enchaînement des actions de l'équipage ayant conduit à l'accident seront analysées.

Le troisième axe repose sur l'observation d'équipages (activités, communications,...) dans des conditions de vols réels. Le type de vol retenu dépendra des résultats des questionnaires et des entretiens. Ces observations ont pour objectif de rechercher dans la gestion du vol les facteurs susceptibles de générer les états de fatigue.

Enfin, le quatrième axe constitue davantage une approche expérimentale de la fatigue et cherchera à mettre en évidence ses composantes cognitives.

Les résultats devraient permettre de répondre à plusieurs questions concernant la prévision et la détection des états de fatigue. Ces étapes constituent les bases nécessaires à l'élaboration de solutions efficaces permettant de réduire l'impact de la fatigue sur la sécurité des vols.

- REMERCIEMENTS -

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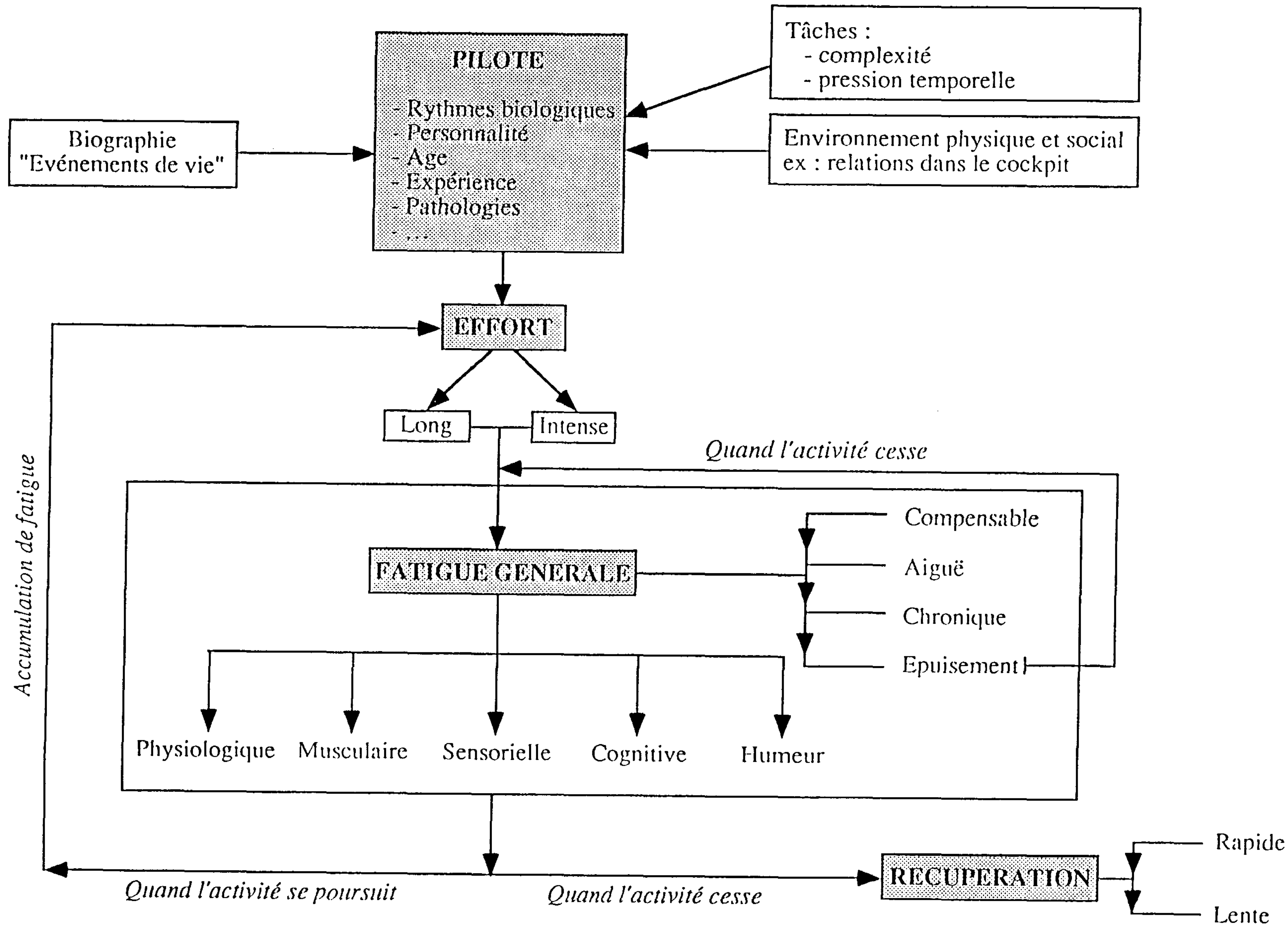

Figure n°3 : Bases d'un modèle de la fatigue en aéronautique

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SIMULATION D'UNE MISSION AERIENNE SOUTENUE ET RÉPERCUSSIONS SUR LE NIVEAU DE VIGILANCE ET DE PERFORMANCE

(Simulated sustained flight operations and effects on vigilance and performance)

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SUMMARY

Many hours of work and waiting are necessary to prepare a flight operation. Sometimes, cancellation of mission and new programming can result for pilots in tiredness and drowsiness, especially some military operations as multiple, long range, carrier based, air combat missions (US A6 Intruder), maritim patrols (French Atlantics), observations (AWACS). The general schedule of this simulated sustained flight operation is : planning I : 9 hours, rest period (without sleep) : 4 hours, mission I : 14 hours, rest period (with sleep) : 6 hours, planning II : 9 hours, rest period (withou sleep) : 4 hours, mission II : 14 hours, night sleep recovery : 12 hours.

To evaluate the level of vigilance and performance, questionnaires, mood scales, seven computer-administered performance tasks, a computer-administered sensitivity contrast threshold, and multiple sleep latency tests were repeatedly administered to the subjects throughout the experiment. An electroencephologram was also recorded during rest periods. Several physiological measures (heart rate, blood pressure, core temperature) were also obtained at regular intervals. After a training period eight healthy volunteers, military men were included in this study. The results show that the effects of this kind of sleep disturbance is limited. In fact, the most sensitive tasks were the memory search task ($p<0.05$) 2 and 4 letters, the tracking task ($p<0.05$) and the double task ($p<0.05$). The sleep latencies decreased more quickly during the second period of 27 hours sleep deprivation than during the first one. The same phenomenom was observed with the items : clumsiness, drowsiness and tiredness of the analog visual scale. No significant perturbation of temperature, heart rate and blood pressure rhythms was seen.

This simulated sustained flight operation show a restricted but real perturbation of vigilance and efficiency. Recovery is observed after the diurnal nap, but it is limited in intensity and duration. These data suggest that the nap is an interesting counter-measure for limited sleep deprivation but also that in case of repeated limited sleep deprivation or a more extensive sleep deprivation others counter-measures, like pharmacological substances, must be used.

RESUME

La préparation d'une mission aérienne demande des heures de travail et des heures d'attente, avant d'avoir lieu et de demander elle-même des heures d'attention soutenue. Parfois l'annulation d'une mission, puis la programmation d'une nouvelle mission provoquent chez les pilotes en attente une fatigue évidente. Certaines missions de bombardement (avec les A6 Intruder américains), de patrouilles maritimes (avec les Atlantics de la Marine Nationale) ou de surveillance (avec les avions de type AWACS) correspondent globalement à ce schéma général de préparation, puis de mission. Le protocole général de la mission simulée d'attaque à grande distance est le suivant : plan de pré-vol n°1 : durée 09 heures ; phase de repos : durée 04 heures ; scénario de la mission n°1: durée 14 heures ; phase de repos avec sommeil : durée 06 heures ; plan de pré-vol n°2 : durée 09 heures; phase de repos : durée 04 heures ; scénario de la mission n°2 : durée 14 heures ; nuit de récupération : durée 12 heures.

Tout au long des phases opérationnelles, pré-vol et scénario, et de façon répétitive, les tests et mesures suivants sont effectués : sept tests psychomoteurs appartenant à l'AGARD STRES Battery, le MSLT, les mesures de la tension artérielle, de la fréquence cardiaque et de la température corporelle, les échelles visuelles analogiques et questionnaires portant sur l'humeur, et la vigilance. L'étude porte sur un groupe de 8 sujets militaires volontaires sains, et est précédée par un entraînement aux tests.

Il apparaît que les effets d'une privation de sommeil modérée (deux fois 27 heures) sur les performances psychomotrices des sujets sont limités. En effet seuls certains tests diffèrent sur le plan statistique (ANOVA). C'est ainsi que les tâches les plus sensibles sont les tâches de recherche en mémoire, 2 et 4 lettres ($p<0.05$), la poursuite visuo-motrice ($p<0.05$) et la double-tâche ($p<0.05$). Les latences d'endormissement décroissent rapidement et ce de façon plus importante lors de la session située après la période de sommeil diurne. Le même phénomène est observé lors de l'étude des items comportementaux (maladroit, somnolent, fatigué...). Aucune modification significative n'est

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observée en ce qui concerne les rythmes de la température, de la fréquence cardiaque, et de la tension artérielle.

En conclusion, cette simulation de mission aérienne met en évidence une perturbation du niveau de vigilance et de performance psychomotrice des sujets. Une récupération est observée après un somme diurne, mais cette récupération est partielle et limitée dans le temps. Ces données doivent être prises en compte dans une stratégie de gestion de la vigilance.

INTRODUCTION

La préparation d'une mission aérienne demande des heures de travail et des heures d'attente, avant d'avoir lieu et de demander elle-même des heures d'attention soutenue. Parfois l'annulation d'une mission, puis la programmation d'une nouvelle mission provoquent chez les pilotes en attente une fatigue évidente. Certaines missions de bombardement (avec les A6 Intruder américains), de patrouilles maritimes (avec les Atlantics de la Marine Nationale française) ou de surveillance (avec les avions de type AWACS) correspondent globalement à ce schéma général de préparation, puis de mission. Il s'agit d'une opération soutenue c'est-à-dire "présentant un programme de travail qui dépasse en temps un cycle habituel, se traduisant par de la fatigue et un manque de sommeil, et rencontrée le plus souvent lors de séances d'entraînement et de missions de combat à terre ou dans les airs" (Néri and Gadolin, 1990). Il nous est apparu intéressant, en s'inspirant d'un protocole expérimental de simulation d'une mission aérienne dans l'US Navy (Shappel et al., 1992), d'évaluer l'impact de ce type de mission sur le niveau de vigilance et de performance de sujets sains et d'apprécier l'effet de récupération d'un somme diurne.

1) METHODE

Sujets :

Huit sujets volontaires sains ont participé à l'expérimentation. Ils sont âgés de 28 à 47 ans (moyenne : 37,25 ± 5,8). Tous ont été soumis à un examen clinique complet avant d'être sélectionnés. Ils ont signé un protocole de consentement éclairé, en accord avec les règles d'éthique en vigueur et pouvaient se retirer à tout moment.

Protocole :

L'expérimentation s'est déroulée au Laboratoire d'Etudes Médico-Physiologiques de Mont-de-Marsan qui est le département opérationnel de l'Institut de Médecine Aérospatiale du Service de Santé des Armées (IMASSA-CERMA). Le protocole général de mission simulée d'attaque à longue distance est le suivant :

préparation du plan de vol n° 1	: durée = 9 heures
repos sans sommeil (attente)	: durée = 4 heures
réalisation 1ère mission	: durée = 14 heures
sommeil diurne	: durée = 6 heures
préparation du plan de vol n° 2	: durée = 9 heures
repos sans sommeil (attente)	: durée = 4 heures
réalisation 2ème mission	: durée = 14 heures
nuit de récupération	: durée = 12 heures

Tout au long des phases "opérationnelles" : préparation de plan de vol et exécution de la mission, les mesures suivantes ont été réalisées de façon répétitive (cf figure 1):

- MSLT : mesures itératives des latences d'endormissement
- Questionnaires et échelles visuelles analogiques d'évaluation de la vigilance et de l'humeur
- enregistrements électrophysiologiques (EEG, EMG, EOG) pour 4 sujets pendant les phases de sommeil diurne et nocturne

Ces outils d'évaluation ont été validés et décrits par ailleurs (Lagarde et Batejat, 1994).

- examen clinique avec recueil de la pression artérielle, de la fréquence cardiaque et de la température corporelle.

Le moniteur de pression artérielle DINAMAP modèle 1846 a été utilisé pour la surveillance non invasive de la pression artérielle et du pouls des sujets en décubitus dorsal et en orthostatisme (utilisation d'un brassard). La mesure des températures a été réalisée à l'aide d'un thermomètre électronique à affichage digital et signal sonore Philips (utilisation du thermomètre par voie buccale).

- une batterie de sept tests psychomoteurs implantés sur micro-ordinateur compatible IBM PC, validée et recommandée par un groupe de travail de l'AMP/NATO (Lagarde et Batejat, 1994). Ces tests sont les suivants :
- Une tâche de temps de réaction qui permet l'évaluation des cinq étapes de traitement suivantes : traitement de la stimulation ou codage, choix de la réponse, programmation de la réponse motrice, activation motrice et enfin exécution de la réponse avec la mise en place de quatre variables correspondant aux caractéristiques visuelles du stimulus, à la compatibilité entre le stimulus et la réponse, au degré d'incertitude dans l'apparition de la stimulation et enfin à la complexité de la réponse que le sujet doit fournir.
- Une tâche de traitement mathématique qui permet l'évaluation des ressources des processus centraux primaires associés à la mémoire de travail.
- Une tâche de recherche en mémoire qui comprend les étapes suivantes : détection et reconnaissance du stimulus cible, recherche en mémoire et comparaison, sélection de la réponse.
- Une tâche de traitement spatial qui correspond à une mesure des capacités en mémoire visuelle à court terme.
- Une tâche de poursuite destinée à mesurer les ressources utilisées dans l'exécution d'une tâche de contrôle manuel continu.
- Une tâche de raisonnement grammatical qui mesure l'habileté à manipuler des informations grammaticales en utilisant la mémoire de travail.
- Enfin, une double tâche utilisant simultanément la tâche de poursuite et la tâche de recherche en mémoire qui permet la mesure des capacités d'attention divisée.

-un test de sensibilité au contraste permettant d'étudier les effets de la privation de sommeil sur la fonction visuelle. La mise en oeuvre de ce test a fait l'objet d'une publication antérieure (Gommeaux et al., 1993)

Déroulement de l'expérimentation

Compte tenu du matériel disponible, l'apprentissage comme l'ensemble des sessions expérimentales sont

effectués par groupes de quatre sujets, déterminés par tirage au sort (Groupe A - Groupe B).
Le programme est le suivant :

lundi 21H00 arrivée des huit sujets
22H00 coucher
(enregistrement EEG pendant la nuit pour 4 sujets tirés au sort dans les deux groupes)

mardi 06H00 lever
06H30 petit déjeuner
07H00 questionnaires
examen clinique
08H00 STRES battery Groupe A
MSLT Groupe B
09H00 STRES Battery Groupe B
MSLT Groupe A
10H00 sensibilité aux contrastes Gr. A
cabine inclinée Gr. B
11H00 sensibilité aux contrastes Gr. B
cabine inclinée Gr. A
12H00 déjeuner
12H30 questionnaires
examen clinique
13H00 STRES battery Groupe A
MSLT Groupe B
14H00 STRES Battery Groupe B
MSLT Groupe A
15H00 - 19H00 repos sans sommeil
19H00 dîner
20H00 questionnaires
examen clinique
21H00 STRES battery Groupe A
MSLT Groupe B
22H00 STRES Battery Groupe B
MSLT Groupe A
23H00 sensibilité aux contrastes Gr. A
cabine inclinée Gr. B

mercredi 00H00 sensibilité aux contrastes Gr. B
cabine inclinée Gr. A
01H00 simulation de vol
03H00 questionnaires
examen clinique
04H00 STRES battery Groupe A
MSLT Groupe B
05H00 STRES Battery Groupe B
MSLT Groupe A
06H00 sensibilité aux contrastes Gr. A
cabine inclinée Gr. B
07H00 sensibilité aux contrastes Gr. B
cabine inclinée Gr. A
08H00 petit déjeuner
08H30 questionnaires
examen clinique
09H00 - 15H00 sommeil
(enregistrement EEG pour les 4 sujets désignés précédemment)
15H00 réveil
15H30 déjeuner
16H00 questionnaires
examen clinique
17H00 STRES battery Groupe A
MSLT Groupe B
18H00 STRES Battery Groupe B
MSLT Groupe A
19H00 sensibilité aux contrastes Gr. A
cabine inclinée Gr. B
20H00 sensibilité aux contrastes Gr. B
cabine inclinée Gr. A
21H00 dîner
21H30 questionnaires
examen clinique
22H00 STRES battery Groupe A
MSLT Groupe B
23H00 STRES Battery Groupe B
MSLT Groupe A

jeudi 00H00 - 04H00 repos sans sommeil
04H00 souper
05H00 questionnaires
examen clinique
06H00 STRES battery Groupe A
MSLT Groupe B
07H00 STRES Battery Groupe B
MSLT Groupe A
08H00 sensibilité aux contrastes Gr. A
cabine inclinée Gr. B
09H00 sensibilité aux contrastes Gr. B
cabine inclinée Gr. A
10H00 simulateur de vol
11H30 questionnaires
examen clinique
12H00 STRES battery Groupe A
MSLT Groupe B
13H00 STRES Battery Groupe B
MSLT Groupe A
14H00 déjeuner
14H30 sensibilité aux contrastes Gr. A
cabine inclinée Gr. B
15H30 sensibilité aux contrastes Gr. B
cabine inclinée Gr. A
16H30 questionnaires
examen clinique
17H00 dîner
18H00 début nuit de récupération
(enregistrement EEG de la nuit pour les 4 sujets désignés)

vendredi 06H00 lever
06H30 petit déjeuner
07H00 questionnaires
examen clinique
08H00 STRES battery Groupe A
MSLT Groupe B
09H00 STRES Battery Groupe B
MSLT Groupe A
10H00 sensibilité aux contrastes
(Groupes A et B)
11H00 fin.

Entre les différents tests, les sujets sont occupés par le passage à la cabine inclinée du LEMP ou par un simulateur de vol sur micro-ordinateur qui ne donnent pas lieu à des mesures de performance.
Pendant les phases de repos les sujets sont maintenus éveillés et peuvent s'occuper à différentes activités (TV, pétanque, ping-pong, lecture.....)

Analyse statistique :
Les trois premières sessions réalisées en dehors de toute privation de sommeil servent de référence. L'ensemble des résultats a été traité par une analyse de variance ANOVA suivie, quand les conditions étaient requises, d'un test de comparaison multiple de moyennes de Newman-Keuls.

2) RESULTATS

Questionnaire de typage de Horne et Ostberg
75 % de sujets présentent un profil de sommeil de type matin et 25 % plutôt du matin.

Paramètres physiologiques
La mesure de la fréquence cardiaque réalisée par un médecin à l'occasion des examens cliniques, a des valeurs moyennes comprises entre 58 et 72 battements par minute. Celles de la pression artérielle systolique varient de 12 à 13.5 en Hg. Les valeurs de ces deux paramètres diminuent pendant les périodes de repos et sont accrues pendant les phases dites actives. La température centrale oscille en moyenne entre 36.9 et 37.9° Celcius. Elle présente une rythmicité circadienne avec notamment, une baisse importante lors de la phase nocturne entre 03 et 05 heures du matin, et ceci malgré l'état éveillé et actif des sujets (cf figure 2).

Echelles visuelles analogiques sur l'humeur et la vigilance
Au cours des deux phases de 27 heures de privation de sommeil les sujets apparaissent comme de plus en plus fatigués, somnolents et vaseux, et de moins en moins détendus. Le somme diurne permet aux sujets de "récupérer". Cependant lors de la deuxième phase de privation de sommeil, l'amplitude de ces critères est plus grande.
Les items "triste", "déprimé" et "anxieux" n'évoluent pas de façon importante au cours des deux phases de privation de sommeil. Les sujets se sentent plus heureux à l'issue de la nuit de récupération que pendant les privations de sommeil. Par ailleurs, les sujets disent être de moins en moins "en forme" et "énergique" et de plus en plus "maladroit" au cours des privations de sommeil. Là encore ces symptômes subjectifs sont plus intenses et plus précoces lors de la deuxième phase d'éveil que lors de la première. (cf figures 3, 4 et 5).

Mesures itératives des latences d'endormissement
Il est observé une diminution rapide des latences d'endormissement au cours de la première phase de privation de sommeil. C'est ainsi qu'après 22 heures d'éveil continu les sujets s'endorment, en moyenne en moins de 3 minutes. A l'issue de la phase de repos diurne avec sommeil, les valeurs des latences redeviennent voisines des valeurs de référence, puis rechutent rapidement lors de la deuxième phase d'éveil prolongé. En dépit d'une diminution régulière des latences d'endormissement, fonction de l'accroissement de la privation de sommeil, une rythmicité circadienne est retrouvée (cf figure 6).

Enregistrement électroencéphalographique des phases de repos
Les enregistrements électroencéphalographiques réalisés permettent de vérifier l'architecture du sommeil diurne et du sommeil nocturne de récupération. Ces deux phases de sommeil, bien que de durées différentes, présentent une architecture voisine, avec la présence de tous les stades de sommeil, organisés selon le pattern habituel c'est-à-dire avec une prédominance de sommeil lent profond (stades 3 et 4) pendant la première moitié et du sommeil paradoxal pendant la deuxième (cf hypnogramme figure 7).

Fonction de sensibilité au contraste coloré
Comme cela est observé sur la figure n° 8, il apparaît lors de la première phase d'éveil après 24 heures de privation, une augmentation non significative du seuil de sensibilité dans les basses fréquences. Il paraît exister un léger effet bénéfique du somme mais là encore non statistiquement significatif, se traduisant par une faible récupération du seuil de sensibilité au contraste. Puis on observe le maintien de la sensibilité au contraste avec une tendance à l'amélioration qui pourrait s'expliquer par un effet de répétition des tests pendant la semaine. Les valeurs sont encore améliorées après la nuit de récupération.

Tests psychomoteurs
Tâche de temps de réaction
La tâche de temps de réaction est très peu modifiée.
Pour le temps de réaction de base, dans lequel le sujet doit répondre avec l'index ou le majeur de la main droite ou de la main gauche selon la nature et la position de la stimulation à droite ou à gauche de l'écran, on observe que la performance se maintient au même niveau malgré les deux périodes de privation de sommeil. Il existe une faible variation circadienne de la performance non significative sur le plan statistique. La période de six heures de sommeil, bien que courte et diurne, est suffisante pour maintenir la performance à son niveau de base malgré la dette de sommeil accumulée.
Il en est de même pour toutes les autres conditions expérimentales.
Dans le module codé, dans lequel les stimulations apparaissent plus ou moins dégradées, on n'observe aucune différence significative au cours de l'expérimentation.
Mêmes observations pour le module de délai incertain, dans lequel le délai d'apparition des stimulations est aléatoire, le module complexe dans lequel le sujet doit utiliser trois touches différentes pour chaque réponse et pour le module inversé dans lequel la réponse est donnée avec la main opposée au côté d'apparition de la stimulation sur l'écran.
Tâche de traitement mathématique
Il n'existe pas de différences significatives, la période de sommeil semble avoir un effet suffisant pour maintenir la performance pendant la deuxième période expérimentale à un niveau identique à celui de la première période.
Les taux d'erreurs sont faibles et sensiblement identiques (pas de différences statistiquement significatives) tout au

long de l'expérience. On observe également l'apparition d'une évolution cyclique, non significative, de la performance.

Tâche de recherche en mémoire

Les analyses montrent par contre l'existence d'un effet significatif de l'horaire ($p<0.05$) sur l'ensemble des mesures effectuées sur les temps de réaction et les erreurs pour deux lettres, sur les temps de réaction pour quatre lettres. Cette différence se manifeste par un allongement significatif ($p<0.05$) des temps de réponse pour deux lettres aux sessions de mercredi 04H00 et jeudi 12H00 et à la session de mercredi 04h00 pour quatre lettres et d'une augmentation significative ($p<0.05$) du nombre d'erreurs à la session de jeudi 12h00 pour quatre lettres. Cet effet est plus accentué dans le cas de quatre lettres que dans le cas de deux lettres où il est atténué, en particulier après la période de sommeil. La performance est donc dégradée par 27 heures de privation de sommeil, les sessions de mercredi 04h00 et de jeudi 12h00 étant les deux dernières de chaque période de privation. La prise du nap permet donc de retrouver, malgré le décalage horaire, des conditions identiques en ce qui concerne le niveau de performance pour les deux périodes.

La période de sommeil permet le retour à un meilleur niveau de performance, proche de celui des trois premières sessions considérées comme le niveau de performance témoin.

L'évolution circadienne de la performance, bien que non significative, est également plus accentuée, pour la tâche de recherche en mémoire avec quatre lettres (cf figure n° 9).

Tâche de poursuite instable

Aucun effet significatif du facteur horaire sur l'ensemble des données. Cependant on peut observer qu'une augmentation relativement importante de l'indice de déviation se produit aux séances de mercredi 4 heures et jeudi 12 heures.

Il y a très peu de pertes de contrôle d'une manière générale. Leur nombre moyen augmente (jusqu'à 3,5 et 3,75) aux sessions de mercredi 14 heures et de jeudi 12 heures (figure n° 10).

Tâche de traitement spatial

Aucun effet significatif n'est obtenu. En ce qui concerne les temps de réponse, on observe le maintien d'un niveau de performance équivalent tout au long de l'expérimentation. Il n'existe pas de différences non plus en ce qui concerne les taux d'erreurs (figure n° 11).

Tâche de traitement grammatical

L'analyse des temps de réponse obtenus permet de dégager une différence significative entre les sessions expérimentales de mercredi 04h00 et de mercredi 17h00 mettant ainsi en évidence l'effet de la prise du "nap" sur la récupération du niveau de performance.

Une augmentation du nombre d'erreurs est également observée à partir de la session du jeudi 6 heures. La performance présente un rythme circadien avec une légère amélioration des performances aux sessions de milieu de journée et une dégradation à la session de nuit (figure n° 12).

Double tâche

<u>La poursuite</u>:

Il y a un effet horaire qui se traduit par une augmentation significative des indices de déviation aux sessions de mercredi 04h00 et jeudi 06h00 que ce soit avec deux ou quatre lettres (figure n° 13).

La prise du "nap" permet de retrouver un niveau de performance identique au niveau de référence aux sessions de mercredi 17H00 et 22H00. Le nombre de pertes de contrôle est également plus important mais de façon non statistiquement significative, il retombe à zéro après la période de sommeil.

<u>La recherche en mémoire</u> :

Il existe un effet statistiquement significatif du facteur horaire pour deux lettres et pour quatre lettres en ce qui concerne les temps de réponse ($p<0.05$). En ce qui concerne les erreurs les différences ne sont significatives que pour quatre lettres.

Le test de Newman-Keuls permet de situer plus précisément les différences statistiquement significatives. Les augmentations les plus importantes ($p<0.05$) sont observées pour les temps de réponse avec quatre lettres aux sessions de mercredi 04H00, jeudi 06h00 et 12H00. Pour les erreurs, les sessions les plus dégradées ($p<0.05$) sont celles de mercredi 04h00 et de jeudi 12h00.

3) DISCUSSION

Ce travail dont le but était d'une part d'évaluer le niveau de vigilance et de performance de sujets dans le cadre d'une simulation de mission aérienne soutenue et d'autre part d'évaluer l'intérêt de la prise d'un somme dans la récupération de l'efficience, fait suite à une expérimentation de 60 heures de privation de sommeil continue réalisée en laboratoire (Lagarde and Batejat, 1994). L'ensemble des tests mis en oeuvre, validés antérieurement, permet de mettre en évidence une dégradation du niveau de vigilance malgré la durée limitée de la privation (27 heures) et ceci lors des deux phases d'éveil. Cette altération de la vigilance a été objectivée par des tests comme la mesure itérative des latences d'endormissement et à un moindre degré par l'étude de la fonction de sensibilité au contraste. Mais cette perturbation a également été ressentie, de façon statistiquement significative, sur le plan subjectif par des données issues du renseignement des échelles visuelles analogiques dont l'usage se confirme être un fidèle reflet des capacités des sujets. Ces résultats concernant la dégradation du niveau de vigilance sont en accord avec la plupart des études (Karttunen, 1995) et travaux (Webb, 1985 ; Haslam, 1985 ; Rogers et al., 1989 ; Nicholson et al., 1985). L'aspect spécifique de la fonction visuelle, dégradée mais pas de façon significative, est également en accord avec un travail récent de Quant (1992) qui n'observe une dégradation de la fonction de sensibilité au contraste pour les basses fréquences qu'à partir de la 48ème heure d'éveil continu.

L'effet bénéfique de la prise d'un petit somme (nap) a été largement étudié dans la littérature (Bonnet and Arand,

1995 ; Nicholson et al., 1985). L'originalité de ce travail réside dans la situation diurne de ce nap (de 09 à 15H00) et dans sa durée (6 heures). Les résultats obtenus à l'issue de cette période de sommeil sont tout à fait comparables à ceux obtenus au début de l'expérimentation avant une privation de sommeil. Ceci montre que la situation réputée peu récupératrice du nap est compensée par sa durée, lui permettant d'avoir un sommeil dont l'architecture est comparable à celle d'un sommeil nocturne. En revanche, la réapparition des dégradations de la vigilance, est pour certains paramètres plus rapide et un peu plus intense.

Cette observation nous conduit à deux remarques. La première est que le somme dans les conditions où il a été pris, ne permet pas une récupération complète des capacités du sujet. La deuxième est qu'en cas de répétition d'une troisième séquence de ce protocole de mission, d'une réduction de la durée du somme, ou d'un allongement des périodes d'éveil, l'efficience des sujets risque d'être dégradée plus rapidement.

Concernant l'évolution des performances psychomotrices, les résultats montrent qu'une privation de sommeil limitée a des effets limités sur le niveau de performance obtenu à l'ensemble des tests. Les tâches dégradées lors de la première phase de 27 heures sans sommeil sont la tâche de recherche en mémoire, la tâche de raisonnement grammatical, la double-tâche dans ces deux composantes et dans une moindre mesure la tâche de poursuite. Ces résultats sont en accord avec ceux d'études portant sur des durées similaires de privation de sommeil bien que les tests et les conditions expérimentales utilisés soient différents d'une étude à l'autre. C'est ainsi que Williams et al. (1959) ont montré qu'une privation de sommeil de 24 heures détériore la performance de rappel en mémoire immédiate. Ces résultats ont été confirmés par Elkin et Murray (1974) et Polzella (1975). De même Hockey (1970) observe une détérioration de la performance dans une double-tâche après 30 heures de privation de sommeil.

Ces résultats sont également conformes à ceux obtenus à ces mêmes tests dans une expérimentation sur les effets d'une privation de sommeil de longue durée réalisée au laboratoire. En effet, lors d'une privation de sommeil de 60 heures, on observe une dégradation générale de la performance en fonction de la durée de la privation de sommeil. Cependant cette évolution n'est pas la même pour toutes les tâches. La dégradation est plus ou moins importante et apparaît plus ou moins tôt au cours de l'expérience. La tâche de temps de réaction est faiblement modifiée alors que les tâches de poursuite, de traitement spatial et de raisonnement grammatical sont très perturbées, surtout à partir de 44 heures de privation de sommeil. La dégradation apparaît dès 26 heures de privation de sommeil pour la tâche de traitement mathématique. La recherche en mémoire est également affectée par une privation de sommeil de 26 heures, particulièrement dans le cas de la mémorisation de quatre lettres, ce qui se traduit surtout par une augmentation importante du nombre d'erreurs. Enfin, dans la double-tâche, poursuite et recherche en mémoire sont également perturbées dès la première nuit (Lagarde et Batejat, 1994). Ces résultats confirment également l'existence d'une variation circadienne des performances plus ou moins importante selon les tests bien que non statistiquement significative, qui est maintenue tout au long de l'expérimentation. La même observation a été réalisée lors de la privation de sommeil de soixante heures qui a également permis la mise en évidence d'une accentuation de ce phénomène pour certaines tâches (Batejat et Lagarde, 1992). Les tests les plus sensibles aux variations circadiennes sont le traitement mathématique, le raisonnement grammatical, la poursuite et la double-tâche. Pour la plupart des tâches utilisées dans l'ensemble des recherches sur ce sujet, l'optimum de performance se situe plutôt l'après-midi et en début de soirée (Hockey et Colquhoun, 1972), cependant de nombreuses études (Baddeley, 1986 ; Folkard et Monk, 1980) ont montré que la mémoire immédiate est plus efficace si le matériel est présenté et restitué tôt le matin. La faible amplitude de cet effet, comparée aux observations réalisées lors de la privation de sommeil de 60 heures, est peut-être dûe au choix des horaires de tests décalés d'une séance à l'autre en raison de l'organisation générale du protocole. Par ailleurs l'étude de Shappel et al. (1992) retrouve des effets de cette perturbation du rythme veille-sommeil, au niveau du test de reconnaissance spatiale, du raisonnement grammatical et du traitement mathématique. Cependant, en dépit de la similarité du protocole général suivi avec notre travail, il est difficile d'établir des comparaisons entre les résultats obtenus, les sujets de l'étude américaine ayant eu la possibilité de dormir ou de ne pas dormir pendant les phases de repos de 4 et 6 heures.

La comparaison de l'évolution des performances aux différents tests pendant une privation de sommeil de soixante heures ininterrompue et au cours de cette dernière expérience pendant laquelle les deux périodes de 27 heures de privation sont séparées par une période de sommeil diurne de 6 heures permet de confirmer l'intérêt du "nap" pour le maintien d'un bon niveau de performance. La performance globalement dégradée par une privation de sommeil de longue durée, dès la première nuit blanche pour certaines tâches retrouve, dans la deuxième période, après la courte période de repos, un niveau identique à celui de la première période de 27 heures.

La performance reste tout à fait constante sur toute la durée de l'expérience pour les différentes conditions de la tâche de temps de réaction et le traitement spatial, hormis une légère influence du rythme circadien. Les différences entre les deux périodes sont minimes pour les tâches de traitement mathématique, recherche en mémoire et raisonnement grammatical. Ces différences semblent plus accentuées pour la tâche de poursuite réalisée seule ou dans le cadre de la double-tâche. Une comparaison plus détaillée est délicate compte tenu du décalage des horaires de test entre les deux périodes et de l'influence du rythme circadien différent selon les horaires.

L'effet bénéfique du nap a été démontré par de nombreuses études. L'intérêt du nap dépend de trois facteurs : sa durée, sa situation au cours du nycthémère et enfin la durée de la privation de sommeil qui le précède. Webb (1987) compare les effets d'une période de sommeil de 4 heures entre 20 et 24 heures et d'une période de 2 heures entre 22 et 24 heures après une nuit de privation de sommeil et montre que la période la plus longue est la plus efficace en terme de performance. Naitoh (1981) montre que après une privation de sommeil de 53 heures, un nap de deux heures situé entre 12 et 14 heures, a un effet plus positif sur la performance qu'un nap de même durée mais pris entre 4 et 6 heures après une privation de sommeil de 45 heures. Enfin Haslam a montré (1981) qu'un groupe expérimenté pouvait rester efficace trois jours sans aucune période de sommeil, six jours avec une période de sommeil de une heure et demi par vingt quatre heures et neuf jours avec des sommes de trois heures.

CONCLUSION

A l'issue de ce travail, trois observations peuvent être faites :

1) une mission aérienne soutenue, telle qu'elle a été simulée ici, est à l'origine d'une réduction des niveaux de vigilance et de performance des sujets.

2) la prise d'un somme permet de récupérer, temporairement, le niveau de vigilance et de performance antérieur.

3) cette mesure physiologique qu'est le "nap" se révèle insuffisante pour redonner le même potentiel de capacité au sujet qu'au début du protocole.

Aussi, il apparaît logique de s'intéresser aux autres mesures, notamment de type pharmacologique, susceptible de permettre aux sujets de garder, le plus longtemps possible le maximum de leur capacité opérationnelle. De nombreux travaux ont été réalisés à cet effet : effets de la tyrosine (Neri et al., 1995), effet des stimulants de type amphétaminiques (Babkoff and Krueger 1992), intérêt du modafinil (Lagarde et al., 1995) (Lagarde and Batejat 1995), utilisation des hypnotiques (Sicard et al., 1995) (Jeanneau and Lagarde, 1990, pour revue), administration de mélatonine et autres psychotropes (Lagarde et Batejat, 1993, pour revue).

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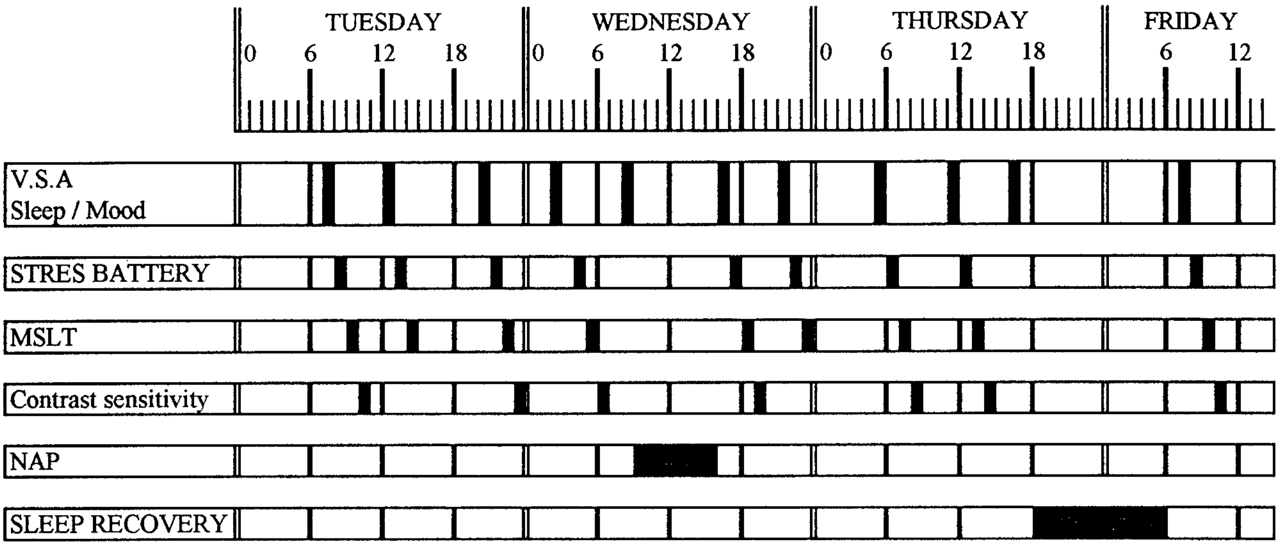


FIGURE 1

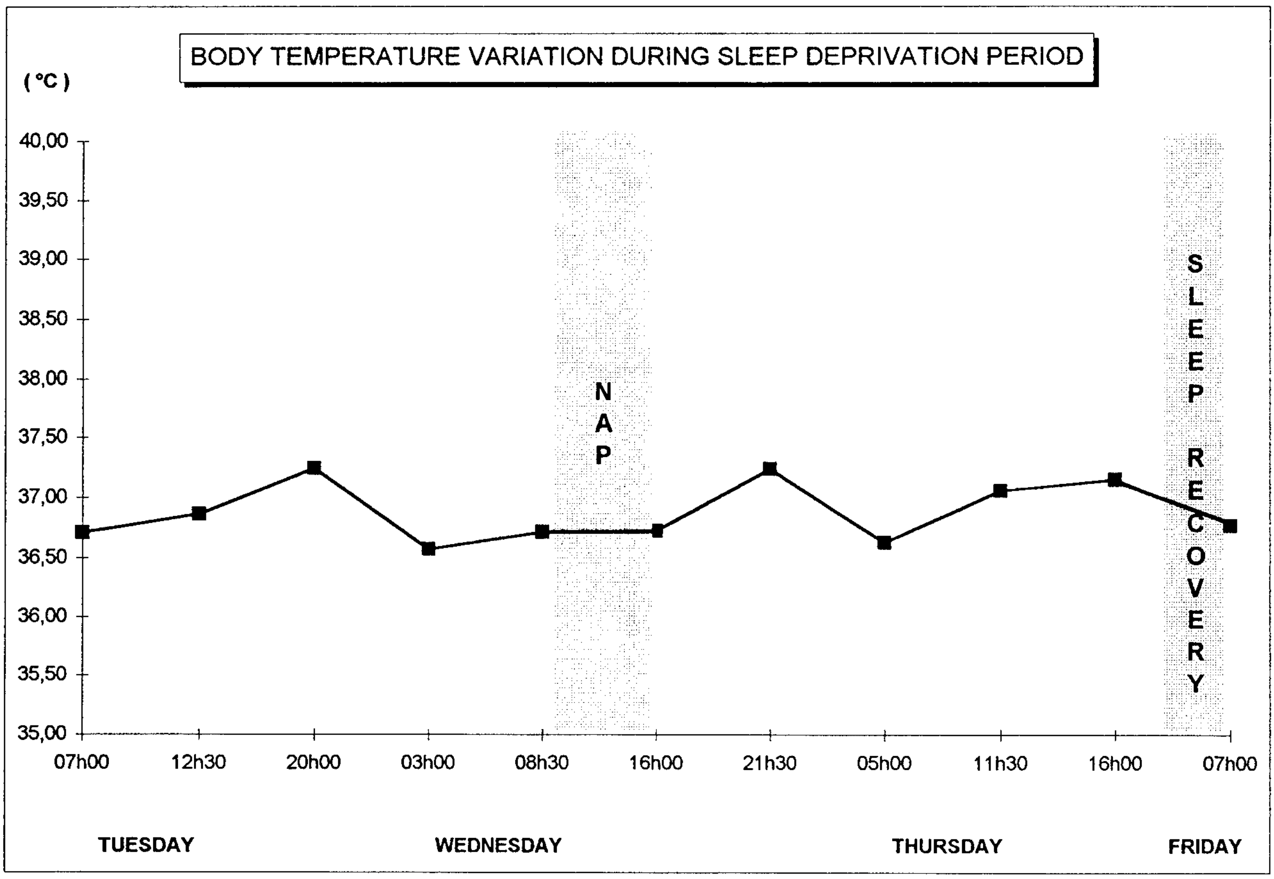


FIGURE 2

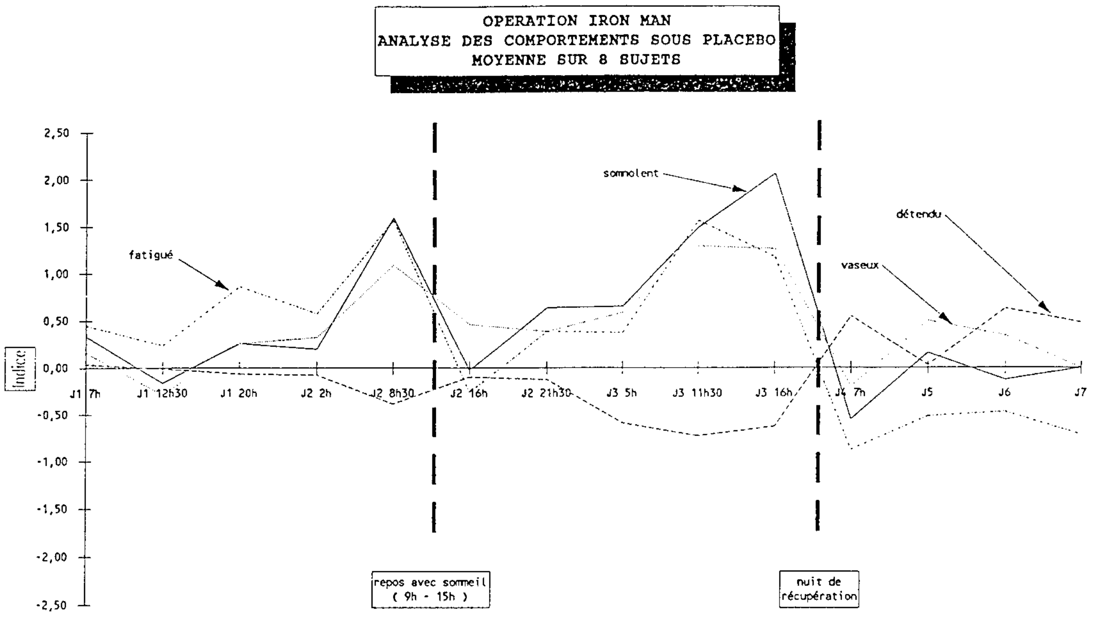
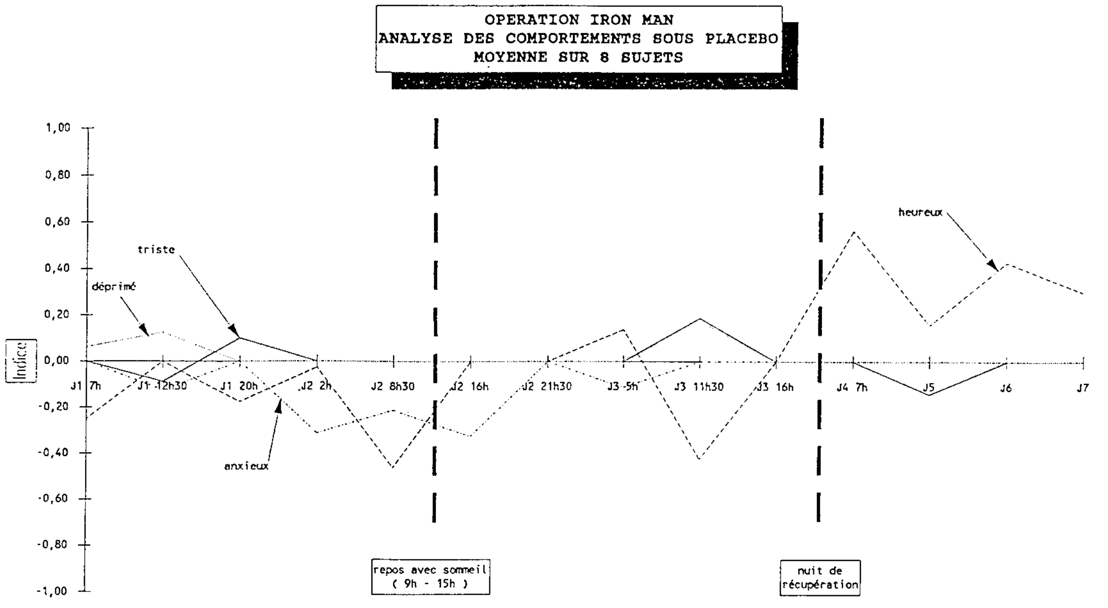


Figure 3



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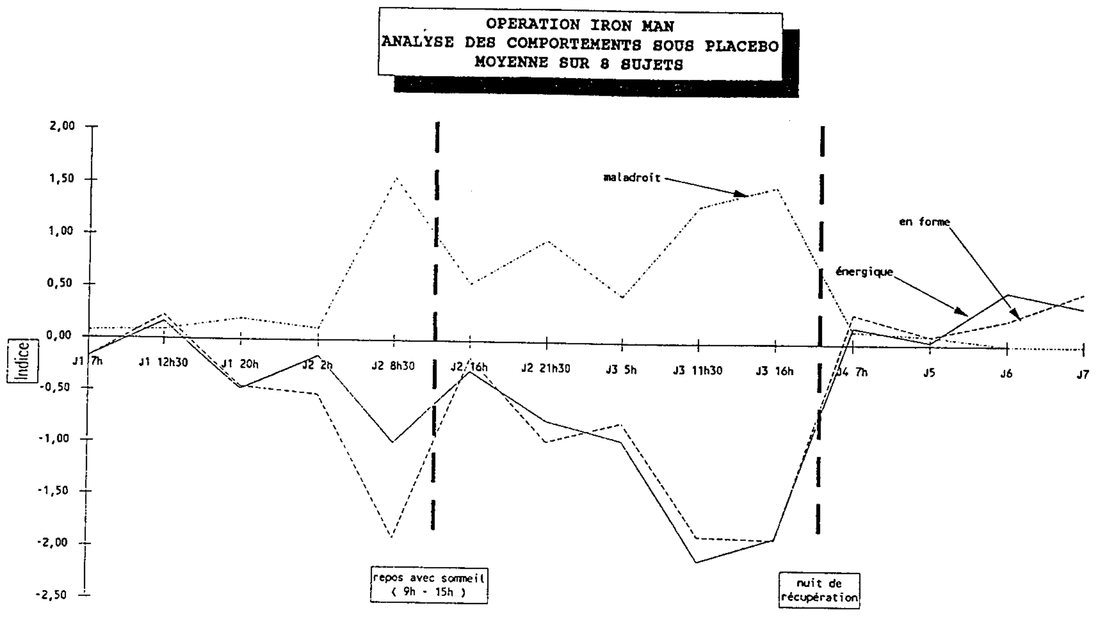
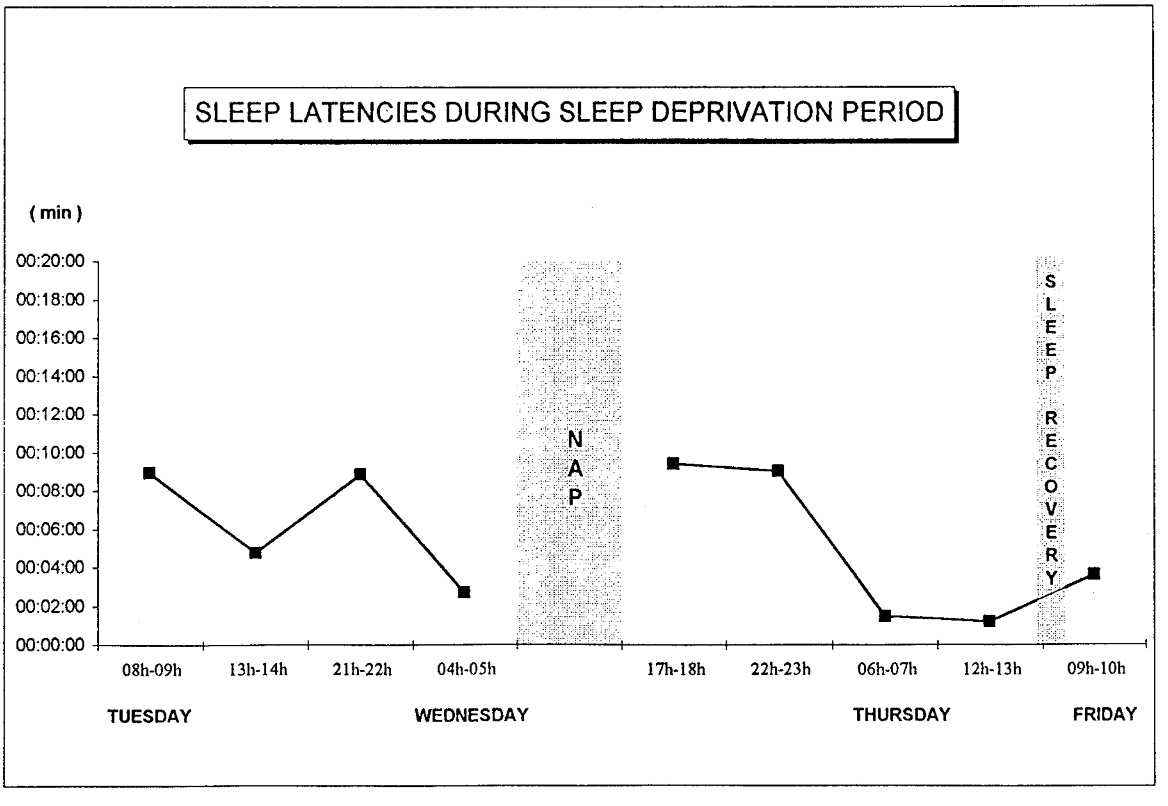


Figure 5



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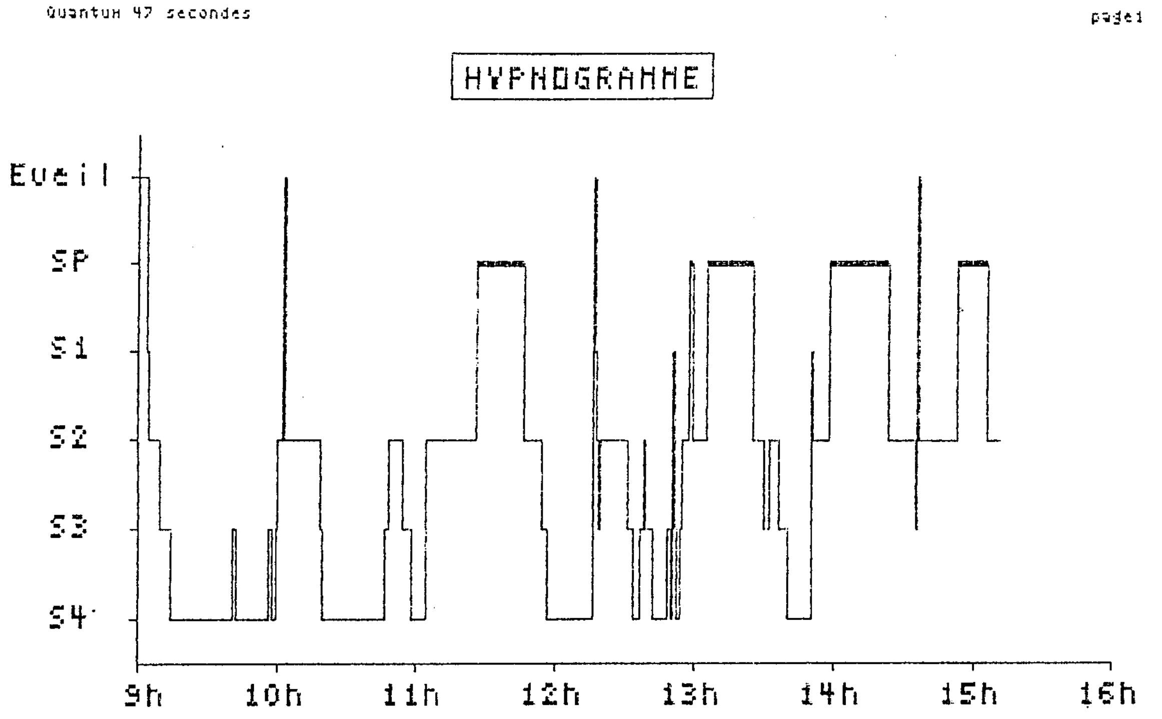
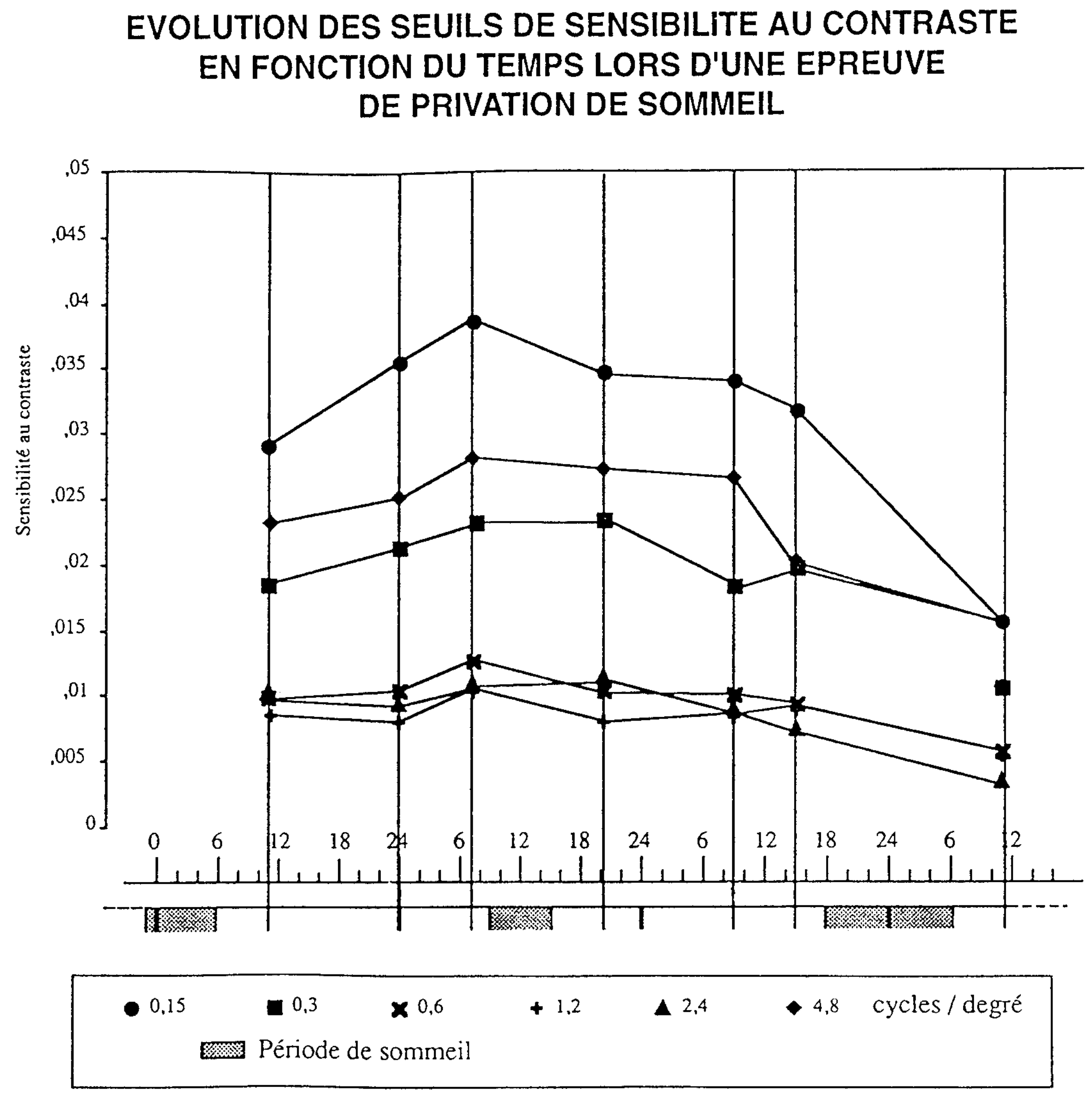


OPERATION IRON-MAN REPOS DIURNE
SESSION PLACEBO SUJET N° 1

Figure 7


EVOLUTION DES SEUILS DE SENSIBILITE AU CONTRASTE
EN FONCTION DU TEMPS LORS D'UNE EPREUVE
DE PRIVATION DE SOMMEIL
Sensibilité au contraste
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0
0 6 12 18 24 6 12 18 24 6 12 18 24 6 12
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cycles / degré
Période de sommeil

Figure 8

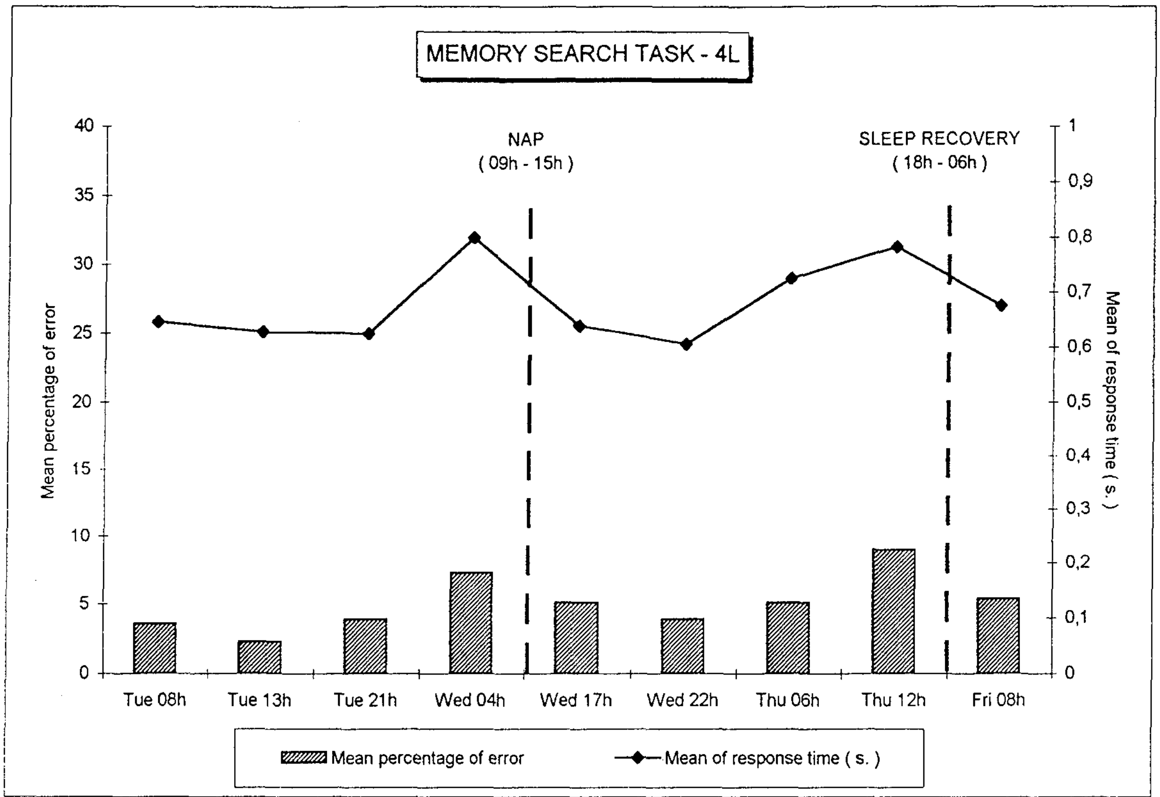
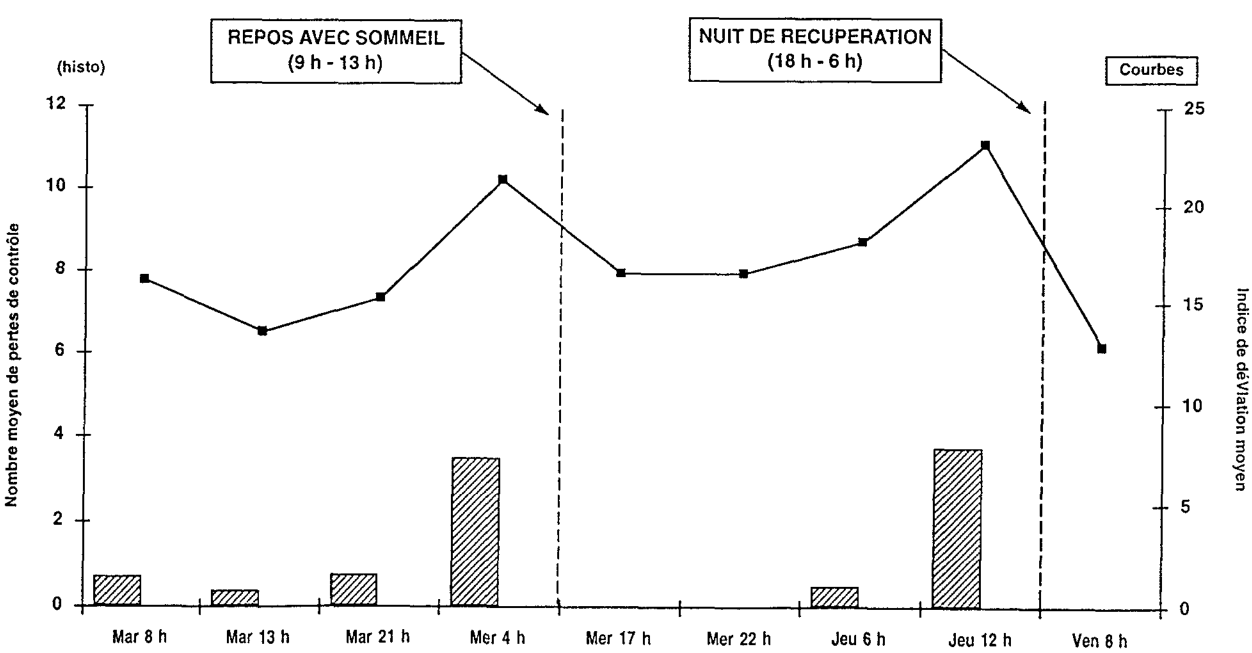


Figure 9

TACHE DE POURSUITE



Tâche de poursuite. Évolution de la performance au cours de l'expérimentation Iron Man : (deux fois 27 heures de privation de sommeil séparées par un somme diurne de 6 heures)

D'après BATEJAT et LAGARDE (1993)

Figure 10

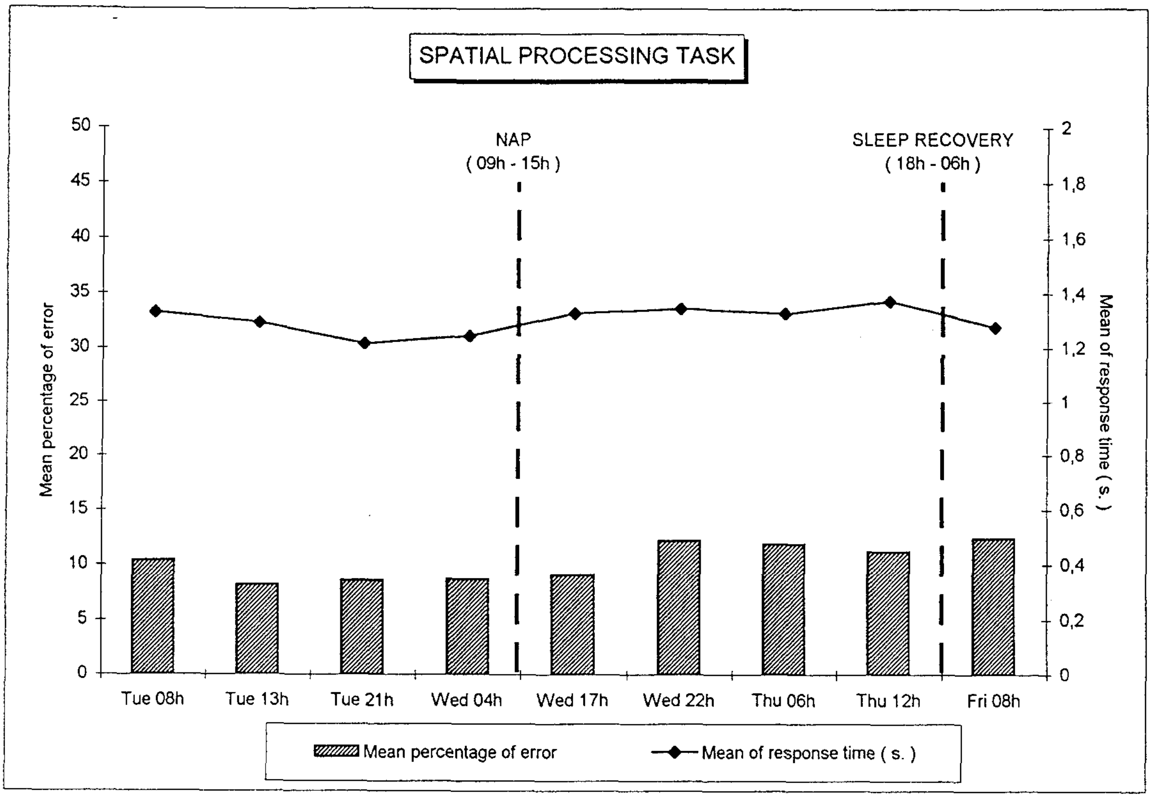


Figure 11

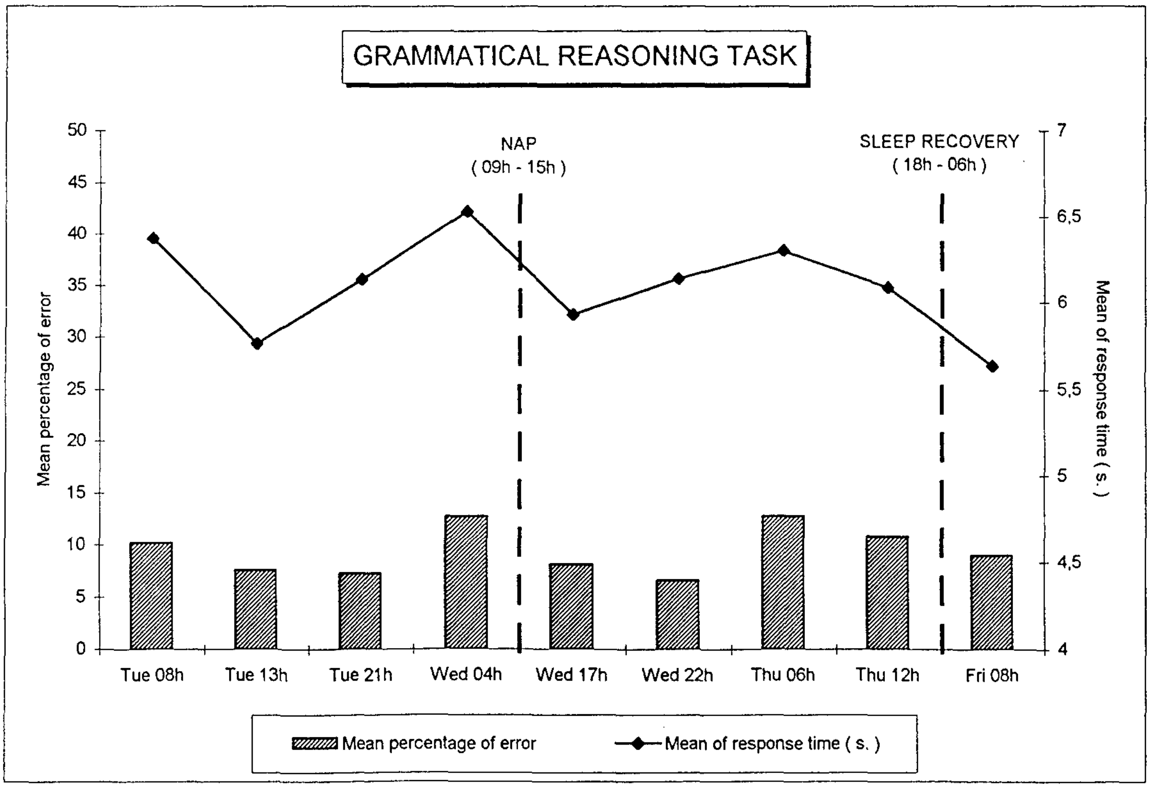


Figure 12

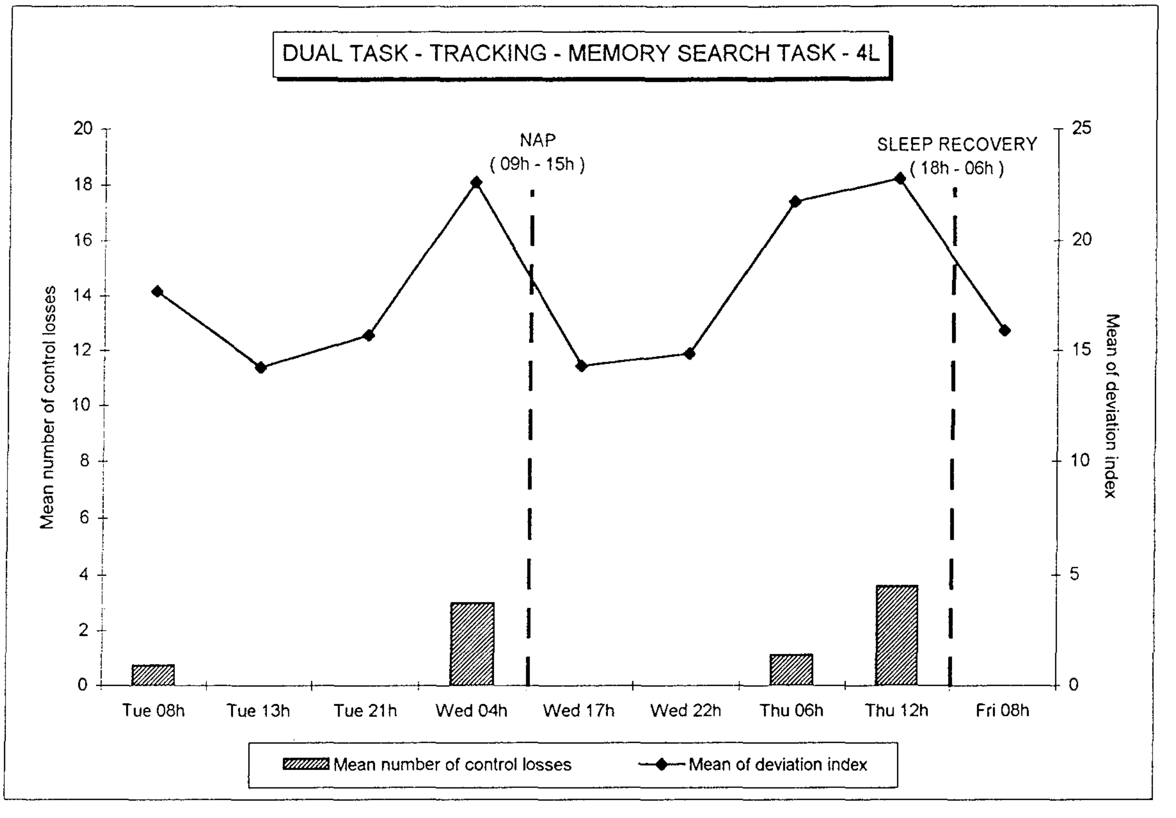

DUAL TASK - TRACKING - MEMORY SEARCH TASK - 4L
NAP
(09h - 15h)
SLEEP RECOVERY
(18h - 06h)
Mean number of control losses
Mean of deviation index
20
18
16
14
12
10
8
6
4
2
0
25
20
15
10
5
0
Tue 08h
Tue 13h
Tue 21h
Wed 04h
Wed 17h
Wed 22h
Thu 06h
Thu 12h
Fri 08h
Mean number of control losses
Mean of deviation index

Figure 13

SIMULATED SUSTAINED FLIGHT OPERATIONS AND EFFECTS ON VIGILANCE AND PERFORMANCE

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SUMMARY

Many hours of work and waiting are necessary to prepare a flight operation. Sometimes, cancellation of mission and new programming can result for pilots in tiredness and drowsiness, especially some military operations as multiple, long range, carrier based, air combat missions (US A6 Intruder), maritim patrols (French Atlantics), observations (AWACS). The general schedule of this simulated sustained flight operation is : planning I : 9 hours, rest period (without sleep) : 4 hours, mission I : 14 hours, rest period (with sleep) : 6 hours, planning II : 9 hours, rest period (withou sleep) : 4 hours, mission II : 14 hours, night sleep recovery : 12 hours.

To evaluate the level of vigilance and performance, questionnaires, mood scales, seven computer-administered performance tasks, a computer-administered sensitivity contrast threshold, and multiple sleep latency tests were repeatedly administered to the subjects throughout the experiment. An electroencephologram was also recorded during rest periods. Several physiological measures (heart rate, blood pressure, core temperature) were also obtained at regular intervals. After a training period eight healthy volunteers, military men were included in this study. The results show that the effects of this kind of sleep disturbance is limited. In fact, the most sensitive tasks were the memory search task ($p<0.05$) 2 and 4 letters, the tracking task ($p<0.05$) and the double task ($p<0.05$). The sleep latencies decreased more quickly during the second period of 27 hours sleep deprivation than during the first one. The same phenomenom was observed with the items : clumsiness, drowsiness and tiredness of the analog visual scale. No significant perturbation of temperature, heart rate and blood pressure rhythms was seen.

This simulated sustained flight operation show a restricted but real perturbation of vigilance and efficiency. Recovery is observed after the diurnal nap, but it is limited in intensity and duration. These data suggest that the nap is an interesting counter-measure for limited sleep deprivation but also that in case of repeated limited sleep deprivation or a more extensive sleep deprivation others counter-measures, like pharmacological substances, must be used.

RESUME

La préparation d'une mission aérienne demande des heures de travail et des heures d'attente, avant d'avoir lieu et de demander elle-même des heures d'attention soutenue. Parfois l'annulation d'une mission, puis la programmation d'une nouvelle mission provoquent chez les pilotes en attente une fatigue évidente. Certaines missions de bombardement (avec les A6 Intruder américains), de patrouilles maritimes (avec les Atlantics de la Marine Nationale) ou de surveillance (avec les avions de type AWACS) correspondent globalement à ce schéma général de préparation, puis de mission. Le protocole général de la mission simulée d'attaque à grande distance est le suivant : plan de pré-vol n°1 : durée 09 heures ; phase de repos : durée 04 heures ; scénario de la mission n°1: durée 14 heures ; phase de repos avec sommeil : durée 06 heures ; plan de pré-vol n°2 : durée 09 heures; phase de repos : durée 04 heures ; scénario de la mission n°2 : durée 14 heures ; nuit de récupération : durée 12 heures.

Tout au long des phases opérationnelles, pré-vol et scénario, et de façon répétitive, les tests et mesures suivants sont effectués : sept tests psychomoteurs appartenant à l'AGARD STRES Battery, le MSLT, les mesures de la tension artérielle, de la fréquence cardiaque et de la température corporelle, les échelles visuelles analogiques et questionnaires portant sur l'humeur, et la vigilance. L'étude porte sur un groupe de 8 sujets militaires volontaires sains, et est précédée par un entraînement aux tests.

Il apparaît que les effets d'une privation de sommeil modérée (deux fois 27 heures) sur les performances psychomotrices des sujets sont limités. En effet seuls certains tests diffèrent sur le plan statistique (ANOVA). C'est ainsi que les tâches les plus sensibles sont les tâches de recherche en mémoire, 2 et 4 lettres ($p<0.05$), la poursuite visuo-motrice ($p<0.05$) et la double-tâche ($p<0.05$). Les latences d'endormissement décroissent rapidement et ce de façon plus importante lors de la session située après la période de sommeil diurne. Le même phénomène est observé lors de l'étude des items comportementaux (maladroit, somnolent, fatigué...). Aucune modification significative n'est

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observée en ce qui concerne les rythmes de la température, de la fréquence cardiaque, et de la tension artérielle.

En conclusion, cette simulation de mission aérienne met en évidence une perturbation du niveau de vigilance et de performance psychomotrice des sujets. Une récupération est observée après un somme diurne, mais cette récupération est partielle et limitée dans le temps. Ces données doivent être prises en compte dans une stratégie de gestion de la vigilance.

INTRODUCTION

Preparing a flight operation requires many hours of work and waiting. Sometimes, mission cancellation and new programming result for pilots in obvious tiredness, especially during some military operations like bombing missions (US A6 Intruder), maritim patrols (French Atlantics) or observations (AWACS). Those sustained operations are featured by overlasting work schedule, tiredness and sleep loss and are often met in training or real missions by land and air (Neri and Gadolin, 1990). We found interesting to evaluate the influence of such missions on vigilance and performance levels and the recuperation brought by a diurnal nap in healthy subjects by drowing our inspiration from an experimental pattern of a US Navy flight mission simulation (Shapell and al, 1992).

1) METHODS

Subjects :

Eight healthy volunteers were included in this study. They were betweeen 28 and 47 (mean : 37.25 5.8). All of them were submitted to a complete clinical examination before their involvment in the experiment. They signed a well informed consent paper according to current regulations and they could retire at any time.

Experimental pattern :

The experiment took place at the Laboratoire d'Etudes Medico-Physiologiques de Mont-de-Marsan, which is the operational department of the Institut de MÈdecine AÈrospatiale du Service de SantÈ des ArmÈes (IMASSA-CERMA). The general pattern of simulated sustained flight operation is described below :

preparation of flight plan 1 :	duration :	9 hours
rest without sleep (waiting) :		4 hours
accomplishment of mission 1 :		14 hours
diurnal sleep :		6 hours
preparation of flight plan 2 :		9 hours
rest without sleep (waiting) :		4 hours
accomplishment of mission 2 :		14 hours
recuperation night :		12 hours

During operational stages (preparation of the flight plan and accomplishment of the mission), the following tests were performed (cf figure 1) :

- MSLT : multiple sleep latency test
- questionnaire and visual analogic scale about vigilance and mood
- electrophysiological recordings (EEG, EMG, EOG) for 4 subjects during the stages of diurnal and nocturnal sleep.

These assessment tools were described elsewhere (Lagarde and Batejat, 1994).

- clinical examination with measure of arterial blood pressure, pulse rate and body temperature. The blood pressure monitor DINAMAP model 1846 allowed us to assess blood pressure and pulse rate by a non invasive way in subjects lying on their back or standing. Temperatures were recorded by a Philips electronic thermometer with digital display and sound signal (oral use).
- a computerized IBM-PC battery of seven psychomotor tests, acknowledged by a working group from AMP/NATO (Lagarde and Batejat, 1994), as followed :

*a reaction time task to test the separate stages of stimulus processing : coding, response choice, motor programming, motor activation and response execution, depending on four visual features of the stimulus : compatibility stimulus/response, incertainty degree of stimulus apparition time and response complexity.

*a mathematical processing task for the evaluation of the primary central processus capacity related to the working memory.

*a memory search task : stimulus detection and acknowledging, memory search and comparison, response sorting.

*a spatial processing task for recording the long term visual memory.

*a tracking task for the evaluation of skills implicated in performing a manual control continuous task.

*a grammar reasonning task for the evaluation of grammatical skills and working memory.

*a double task : tracking and memory search in order to evaluate the multiple attention capacity.

*a contrast sensitivity test for the evaluation of sleep loss consequences on visual fonction (Gommeaux and al., 1993).

Schedule

Owing to available material, training and all experimental sessions were performed by four subjects groups, randomly chosen (Groupe A - Groupe B)

The followed programm is :

monday 21H00 arrival of the eight subjects
22H00 bed time

(EEG recording during the night for 4 subjects in both groups)

tuesday 06H00 getting up
06H30 breakfast
07H00 questionnaires
clinical examination
08H00 STRES battery Groupe A
MSLT Groupe B
09H00 STRES Battery Groupe B

MSLT Groupe A
10H00 contrast sensitivity test Gr. A
inclined cockpit Gr. B
11H00 contrast sensitivity test Gr. B
inclined cockpit Gr. A
12H00 lunch
12H30 questionnaires
clinical examination
13H00 STRES battery Groupe A
MSLT Groupe B
14H00 STRES Battery Groupe B
MSLT Groupe A
15H00 - 19H00 rest without sleep
19H00 dîner
20H00 questionnaires
clinical examination
21H00 STRES battery Groupe A
MSLT Groupe B
22H00 STRES Battery Groupe B
MSLT Groupe A
23H00 contrast sensitivity test Gr. A
inclined cockpit Gr. B

<u>wednesday</u> 00H00 contrast sensitivity test Gr. B
inclined cockpit Gr. A
01H00 flight simulation
03H00 questionnaires
clinical examination
04H00 STRES battery Groupe A
MSLT Groupe B
05H00 STRES Battery Groupe B
MSLT Groupe A
06H00 contrast sensitivity test Gr. A
inclined cockpit Gr. B
07H00 contrast sensitivity test Gr. B
inclined cockpit Gr. A
08H00 breakfast
08H30 questionnaires
clinical examination
09H00 - 15H00 sleep
(EEG recording for the 4 subjects already designed)
15H00 wake-up
15H30 lunch
16H00 questionnaires
clinical examination
17H00 STRES battery Groupe A
MSLT Groupe B
18H00 STRES Battery Groupe B
MSLT Groupe A
19H00 contrast sensitivity test Gr. A
inclined cockpit Gr. B
20H00 contrast sensitivity test Gr. B
inclined cockpit Gr. A
21H00 dîner
21H30 questionnaires
clinical examination
22H00 STRES battery Groupe A
MSLT Groupe B
23H00 STRES Battery Groupe B
MSLT Groupe A

<u>thirsday</u> 00H00 - 04H00 rest without sleep
04H00 souper
05H00 questionnaires
clinical examination
06H00 STRES battery Groupe A
MSLT Groupe B
07H00 STRES Battery Groupe B
MSLT Groupe A
08H00 contrast sensitivity test Gr. A
inclined cockpit Gr. B
09H00 contrast sensitivity test Gr. B
inclined cockpit Gr. A
10H00 flight simulation
11H30 questionnaires
clinical examination
12H00 STRES battery Groupe A
MSLT Groupe B
13H00 STRES Battery Groupe B
MSLT Groupe A
14H00 lunch
14H30 contrast sensitivity test Gr. A
inclined cockpit Gr. B
15H30 contrast sensitivity test Gr. B
inclined cockpit Gr. A
16H30 questionnaires
clinical examination
17H00 dîner
18H00 night beginning of recovery
(EEG recording of the night for the 4 designed subjects)

<u>friday</u> 06H00 getting up
06H30 breakfast
07H00 questionnaires
clinical examination
08H00 STRES battery Groupe A
MSLT Groupe B
09H00 STRES Battery Groupe B
MSLT Groupe A
10H00 contrast sensitivity test
(Groupes A et B)
11H00 end.

Between the tests, subjects went to the LEMP inclined cockpit or to a flight simulator computer where their performances were not measured. During rest stages, subjects were kept awake and could do several activities (TV, game of bowls, ping pong, reading.....).

<u>Statistical analysis</u>

We took as reference the first three sessions performed without sleep deprivation. Results were processed by variance analysis ANOVA and Newman-Keuls mean multiple comparison test if required.

<u>2) RESULTS</u>

<u>Horne and Ostberg sorting questionnaire</u>

75% of the subjects are morning-type and 25% are somewhat morning-type.

<u>Physiological parameters</u>

Pulse rate measured by physicians during clinical examination was on average between 58 and 72 beats per minute. Systolic blood presure was between 12 and 13.5

mm Hg. These numbers decrease for rest periods and increase for active stages. Average central temperature varies between 36.9 and 37.9∞ Celsius. It obeys to a circadian rhythm, showing a clear nocturnal diminution between 3 and 5 am in spite of wakeness and activity (cf figure 2).

Visual analogic scales about vigilance and mood

During both periods of 27 hours sleep deprivation, subjects appear more and more tired, drowsy, washed-out, and less and less relaxed, especially for the second period. The diurnal nap allow them to recuperate. The items "sad", "depressed" and "anxious" don't vary. Subjects are happier at the end of the recuperation night than during sleep deprivations. They report beeing less and less "fit" and "energetic", more and more "clumsy" during sleep deprivations, especially for the second stage (cf figures 3, 4 and 5).

Multiple sleep latency tests

Sleep latencies rapidly decrease during the first period of sleep deprivation. In that way, after a 22 hours continuous wake, subjects fall asleep in less than 3 minutes. At the end of the diurnal sleep, latencies draw nearer to baseline. Then, they suddenly fall during the second stage of sustained wake. In spite of a regular diminution in sleep latencies, depending on sleep deprivation, a circadian rhythm is observed.

Rest stages electroencephalographic recording

Electroencephalographic recordings allow us to investigate sleep structure for diurnal sleep and nocturnal recuperation sleep. Although both sleep stages have not the same duration, they have a similar structure and a classical pattern : prevalence of slow wave sleep for the first half of the night and paradoxical sleep for the second (cf hypnogram on figure 7).

Colored contrast sensitivity

As shown on figure 8, the sensitivity threeshold in the low frequencies does not significantly increases during the first wake period after 24 hours sleep deprivation. Nap seems to have a light favourable effect, but not statistically significant. The next improvement trend could result in test repetition along the week. Values are even better after the recuperation night.

Psychomotor tests

Reaction time task

This task hardly varies. For basic reaction time task, in which subjects have to use their left / right forefinger / major according to the nature and the place of the on screen stimulus, performance level remains constant despite both 27 hours sleep deprivation periods. There is a non significant circadian variation. The 6 hours sleep period is long enough to keep performance near baseline despite sleep loss. It is the same for all other experimental conditions. For coded reaction time, in which stimulus are much or little impaired, there is no significant difference during the experiment. Results are alike for reaction time with random delay of stimulation, for complexe reaction time in which subjects use three distinct buttons for each answer, and for the reversed reaction time in which answer must be given by the opposite hand.

Mathematical processing task

Differences are not significant. Sleep period seems to have enough effect for keeping performance at the same level during the first and second experimental periods. Error rates are weak and fairly identical (no significant statistical difference) all along the experiment. A non significant cyclic evolution can be noticed too.

Memory search task

Results indicate a significant time effect ($p<0.05$) concerning two letters reaction times and error rates, and four letters reaction times. This difference results in a significant extension ($p<0.05$) of two letters response times on wednesday 04:00 and thursday 12:00 and of four letters response times on wednesday 04:00 and in a significant increase ($p<0.05$) in mistake number on four letters on thursday 12:00. This effect is larger in four letters tests than in two letters tests, especially after sleep. Therefore, performance is impaired after 27 hours of sleep deprivation. Nap allow to keep the same performance despite time shift. Sleep make performance level close to that of the first three sessions, regarded as reference. Performance circadian rhythm is emphasized for the four letters memory search task but remains non significant (cf figure 9).

Unstable tracking task

There is no significant time effect. However we can note a fairly good increase in deviation indice on wednesday 04:00 and thursday 12:00. Generally speaking, there is very few control loss. The average number increases (up to 3.5 and 3.75) on wednesday 14:00 and on thursday 12:00 (figure 10).

Spatial processing task.

No significant effect is noted. Reaction times and error rates are constant all along the experiment (figure 11).

Grammatical processing task

There is a significant difference for reaction times between wednesday 04:00 and wednesday 17:00, which illustrates the nap effects on performance recuperation. An increase in error number is noticed after thursday 06:00 session. Performance varies according to a circadian rhythm with a light improvement at the middle of the day and a depreciation during the night (figure 12).

Double task

Tracking :

Time effect consists in a significant increase of deviation indices on wednesday 04:00 and thursday 06:00 with either two or four letters (figure 17). Nap allow to have a performance level similar to baseline level on wednesday 17:00 and 22:00. The number of control loss is non significantly bigger. It returns to 0 after sleep.

Memory search :
There is a significant time effect for two and four letters response time ($p<0.05$). Differences in error rates are significant only for four letters. Newman-Keuls test allow to locate more accurately the significant differences. Bigger increases ($p<0.05$) are noticed for response times with four letters on wednesday 04:00, thursday 06:00 and 12:00. For error rates, the most impaired sessions ($p<0.05$) are on wednesday 04:00 and thursday 12:00.

3) DISCUSSION

This experiment, following a 60 hours sleep deprivation in laboratory (Lagarde and Batejat, 1994), was performed in order to assess vigilance and performance as well as interest of nap, during a simulated sustained flight operation. The different tasks used here and previously validated show vigilance impairment during both wake periods despite the shortness of sleep deprivation (27 hours). Vigilance impairment was significantly suggested by visual analogic scales and objectively demonstrated by multiple sleep latency test. These results about vigilance decrease are similar to those of most studies (Karttunen, 1995 ; Webb, 1985 ; Haslam, 1985 ; Rogers and al., 1989 ; Nicholson and al., 1985). The non significant vision impairment was recently reported by Quant (1992) who noticed a decrease of contrast sensitivities in the low frequencies only after 48 hours of continuous wake.

Favourable effect of nap has been broadly reviewed (Bonnet and Arand, 1995 ; Nicholson and al., 1985). Our experiment was new because of nap features (from 09:00 to 15:00 : diurnal and 6 hours long). Results after nap are similar to results before sleep deprivation. Nap is efficient if it is long enough to have the same internal structure as nocturnal sleep. However, vigilance impairment reappears more rapidly and is more severe for some items. Nap does not bring a complete recuperation. If there was a third period or a shorter nap or longer wake periods, performance would be probably more impaired.

About psychomotor performance, results show that a limited sleep deprivation has limited effects on performance for all tests. The task which were impaired during the first stage of 27 hours wake are memory search, grammatical processing, double task and in some degree tracking task.

We obtained similar results in a laboratory experiment with the same tests. Indeed, there is a performance decrease during a 60 hours sleep deprivation. However, the amplitude and the emergence time of this decrease depends on the task submitted. Reaction time task is weakly altered but spatial processing and grammatical processing are deeply impaired, especially after 44 hours sleep deprivation. Impairment appears after 26 hours for mathematical processing and memory search, especially for four letters memorizing : error number increases. Finally, tracking and memory search during double task are altered as early as the first night (Lagarde and Batejat, 1994). Results show a circadian rhythm, though non significant. Our findings were alike during the 60 hours sleep deprivation experiment, where we discovered a more pronounced effect for some tasks (Batejat and Lagarde, 1992). Clear circadian rhythm are observed for mathematical processing, grammatical processing, tracking and double task. For most tests, the higher performance is obtained in the afternoon or at the beginning of the night (Hockey and Colquhoun, 1972). However, many studies (Baddeley, 1986 ; Folkard and Monk, 1980) revealed a more efficient short term memory in the early morning. The circadian range was weaker than during the 60 hours sleep deprivation because of the test hours, shifted from a session to another. Shapell and al. (1992) reports the influence of wake sleep perturbation on spatial, grammatical and mathematical processing. However, it is hard to compare his results with ours because US subjects could sleep or not during rest periods.

Performance results for this experiment and for the 60 hours sustained wake confirm that nap allow to keep a good performance level. Performance decreases due to sleep loss, and come back to the same level after the nap. Excepting circadian variations, performance remains constant all along the experiment for different models of reaction time and for spatial processing. Difference between both periods are tiny for mathematical processing, memory search and grammatical reasoning. These differences are greater for tracking, alone or from double task. A more detailed comparison is difficult because tests were not performed at the same time for both periods and then results depend partly on circadian rhythm.

Favourable effect of nap was demonstrated by many studies. Three items are involved : nap duration, nap timing and duration of the previous sleep deprivation. Webb (1987) compares two schedules : sleep from 20:00 to 24:00 and sleep from 22:00 to 24:00 after a night without sleep. He concludes : the longer the sleep, the higher the performance. According to Naitoh (1981), after a 53 hours sleep deprivation, a 12:00 / 14:00 nap is better than a 04:00 / 06:00 nap (same duration). Finally, Haslam (1981) reports that experimentated subjects can stay efficient for three days with no sleep, for six days with one hour and a half sleep per day and for nine days with three hours naps

CONCLUSION

The main findings of our study are :

1) a sustained flight operation, as simulated here, impairs vigilance and performance.

2) nap allow subjects to recover for a short time the previous level of vigilance and performance.

3) nap is a valuable countermeasure, but not powerful enough for coming back to the same efficiency level as at the beginning of the experiment. That is why it seems logical to use other countermeasures, especially

pharmacological ones, so that subjects keep as long as possible high operational efficiency. Many studies were made in that purpose : tyrosin (Neri and al., 1995), amphetaminic stimulants (Babkoff and Krueger, 1992), modafinil (Lagarde and al., 1995 ; Lagarde and Batejat, 1995), hypnotics (Sicard and al., 1995 ; Jeanneau and Lagarde, 1990 for review), melatonin and other psychotrops (Lagarde and Batejat, 1993 for review).

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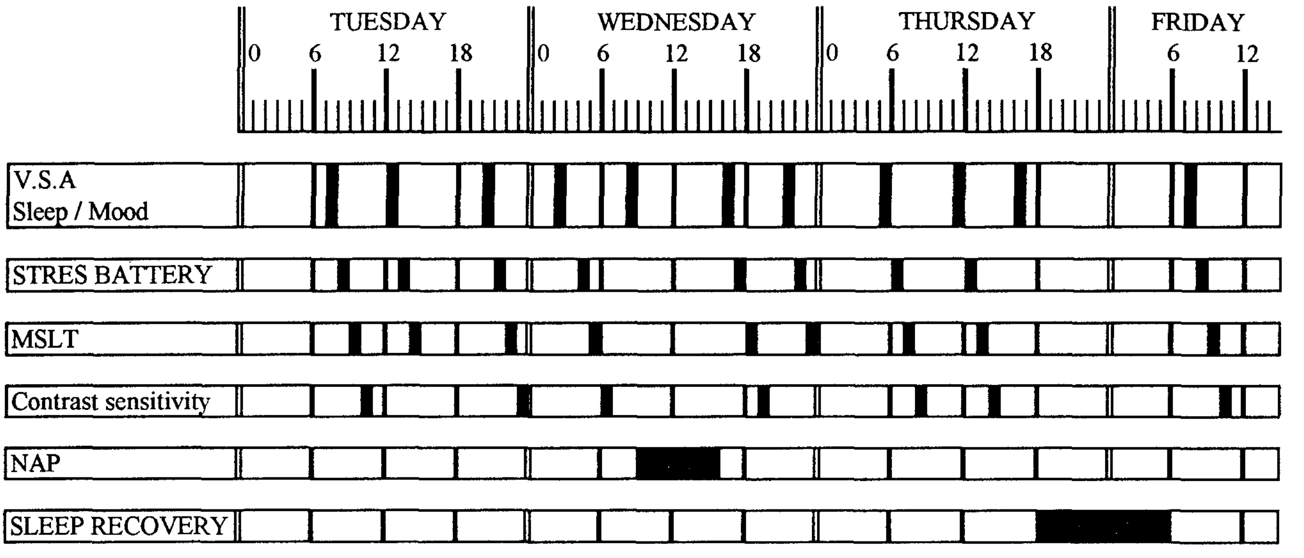


FIGURE 1

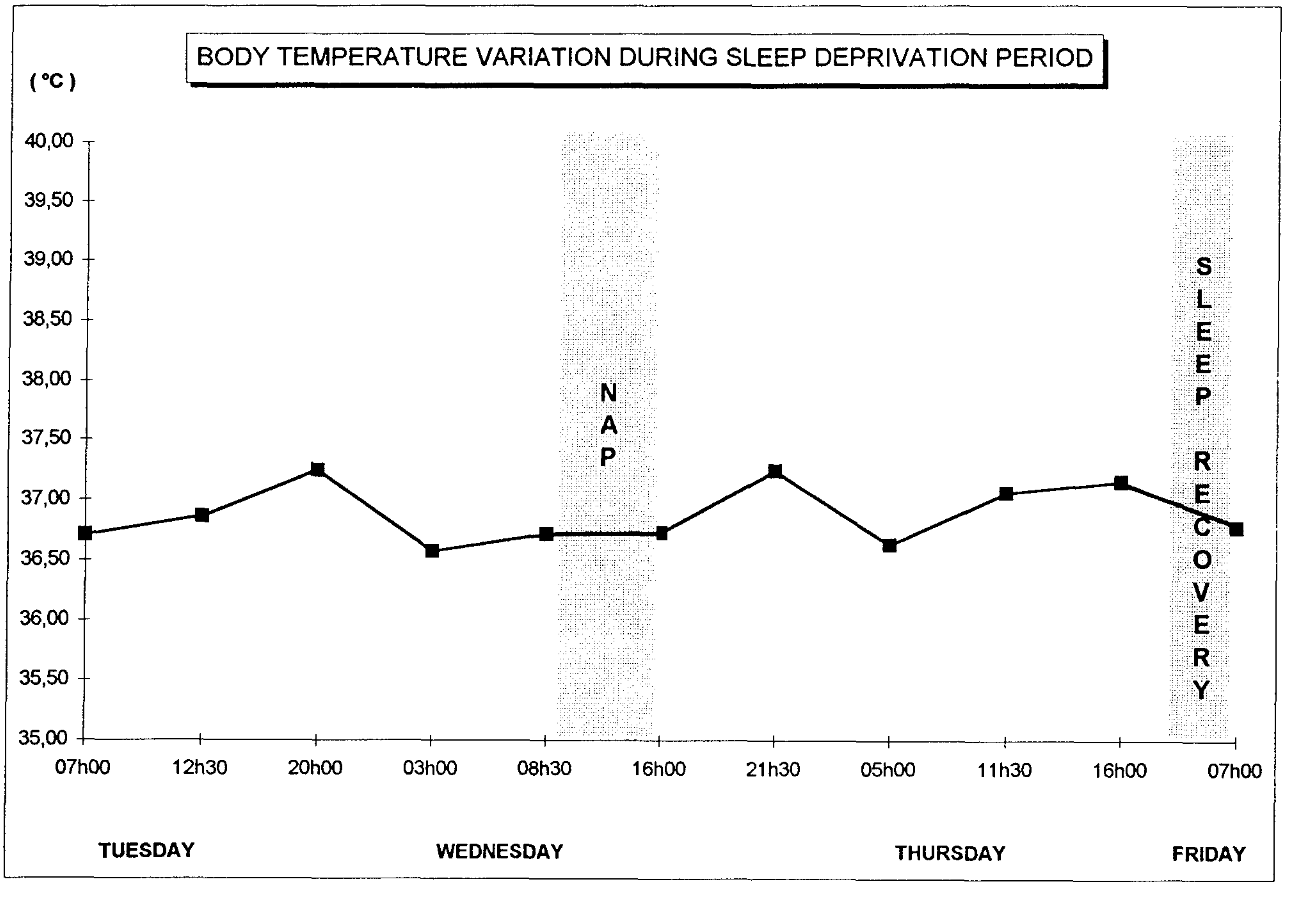


FIGURE 2

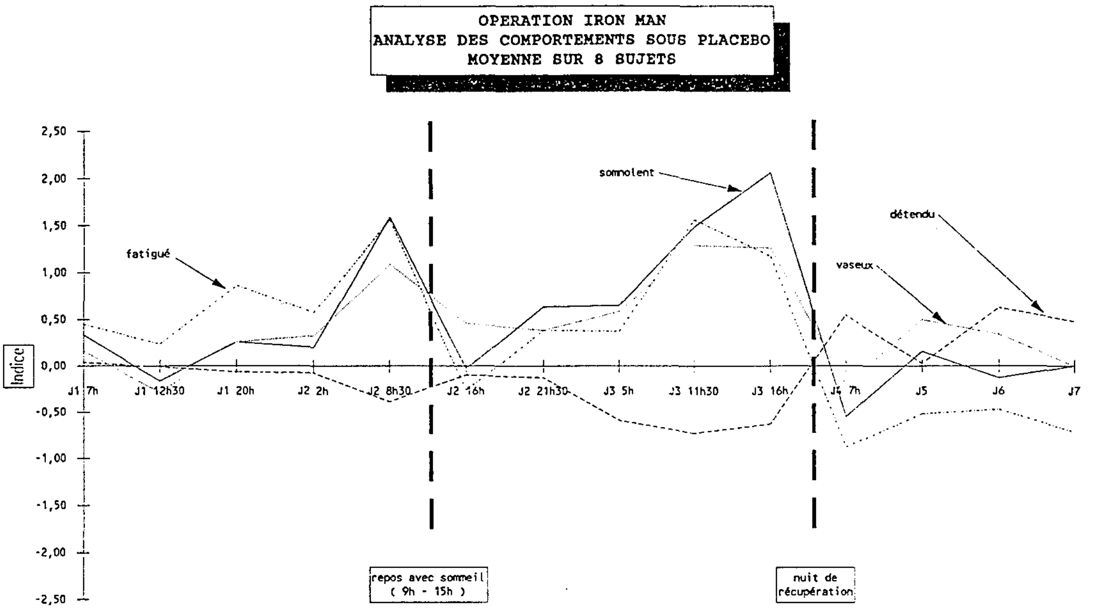


Figure 3

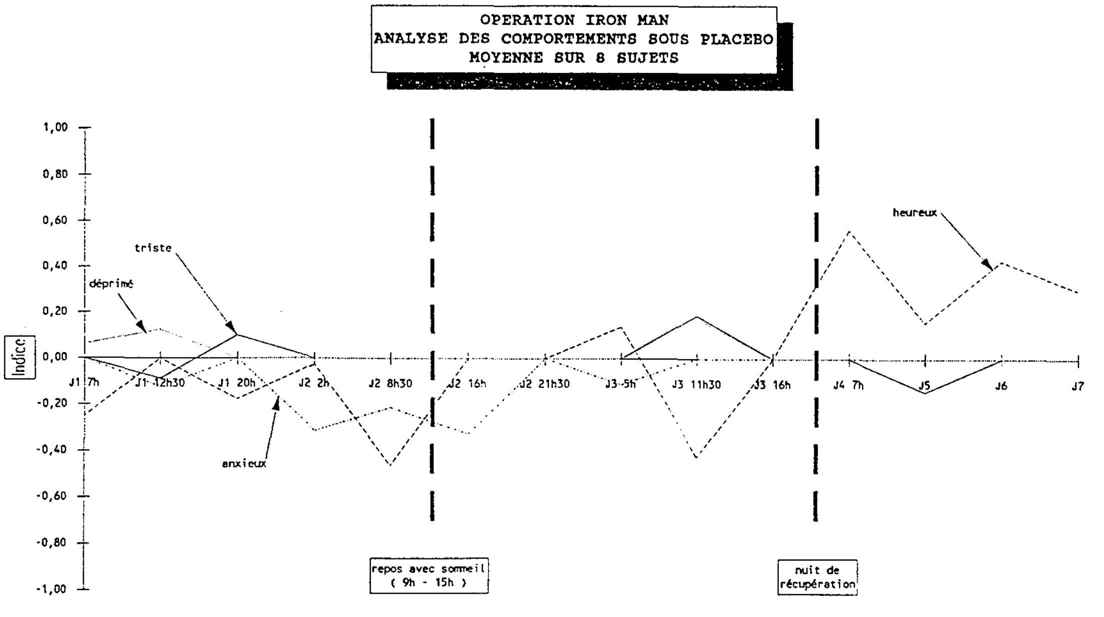


Figure 4

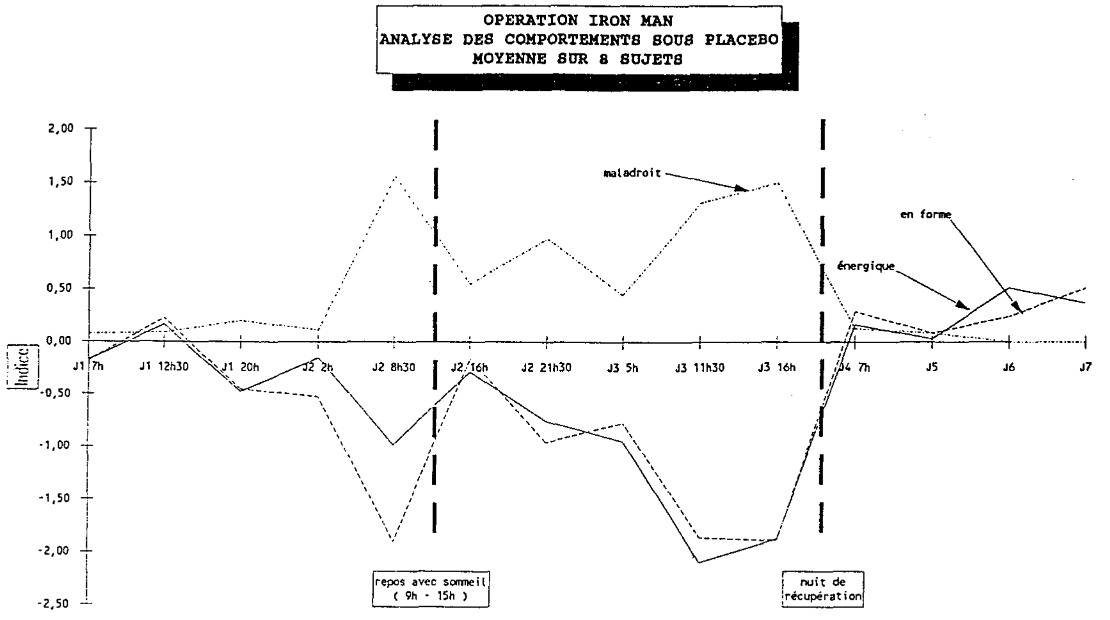


Figure 5

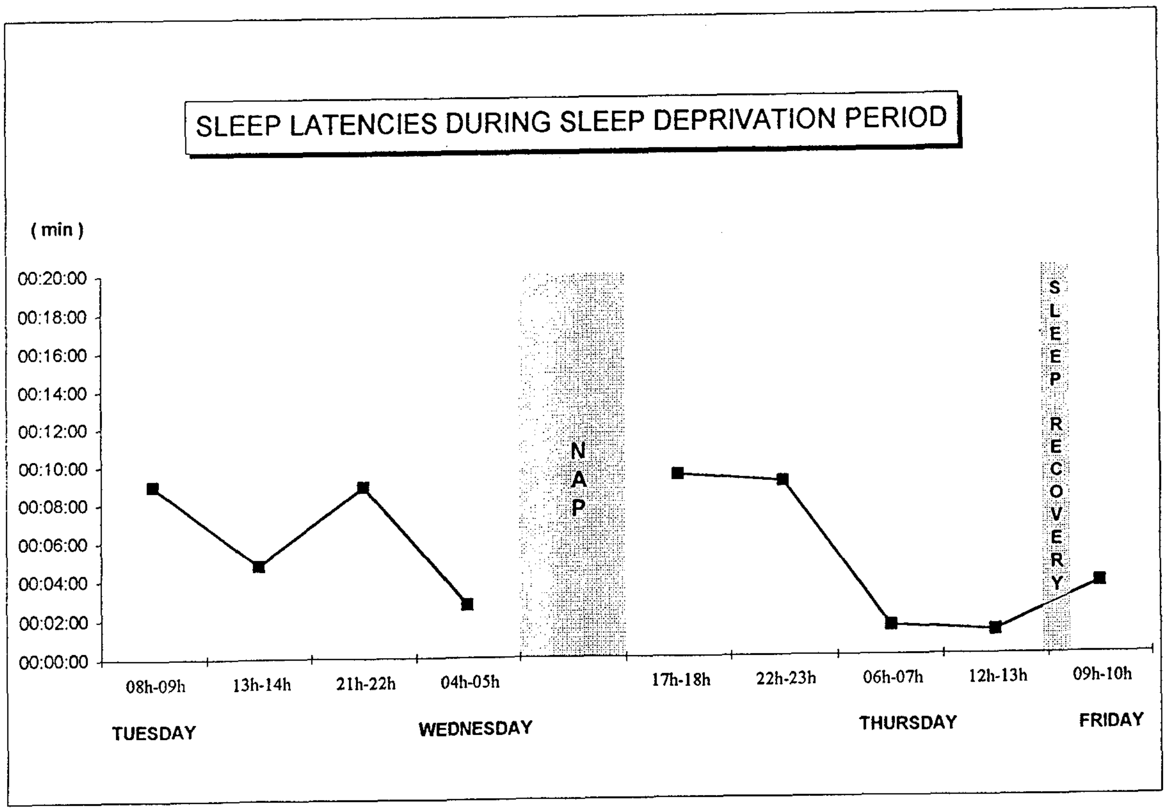
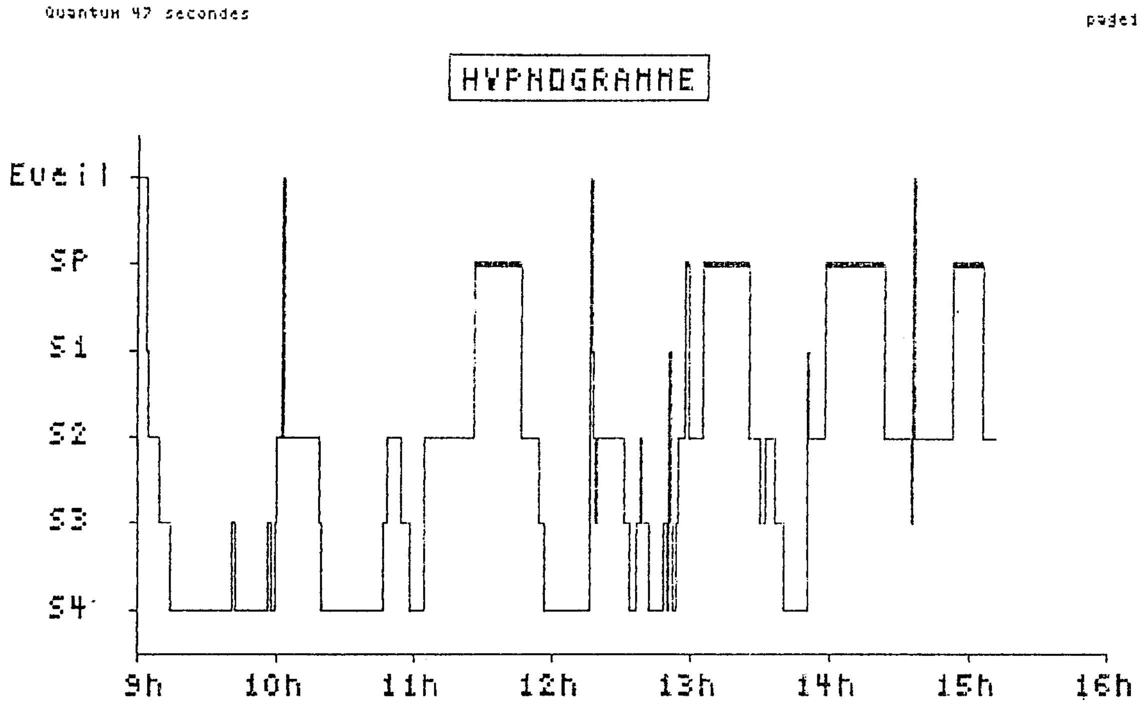


Figure 6



OPERATION IRON-MAN REPOS DIURNE
SESSION PLACEBO SUJET N° 1

Figure 7

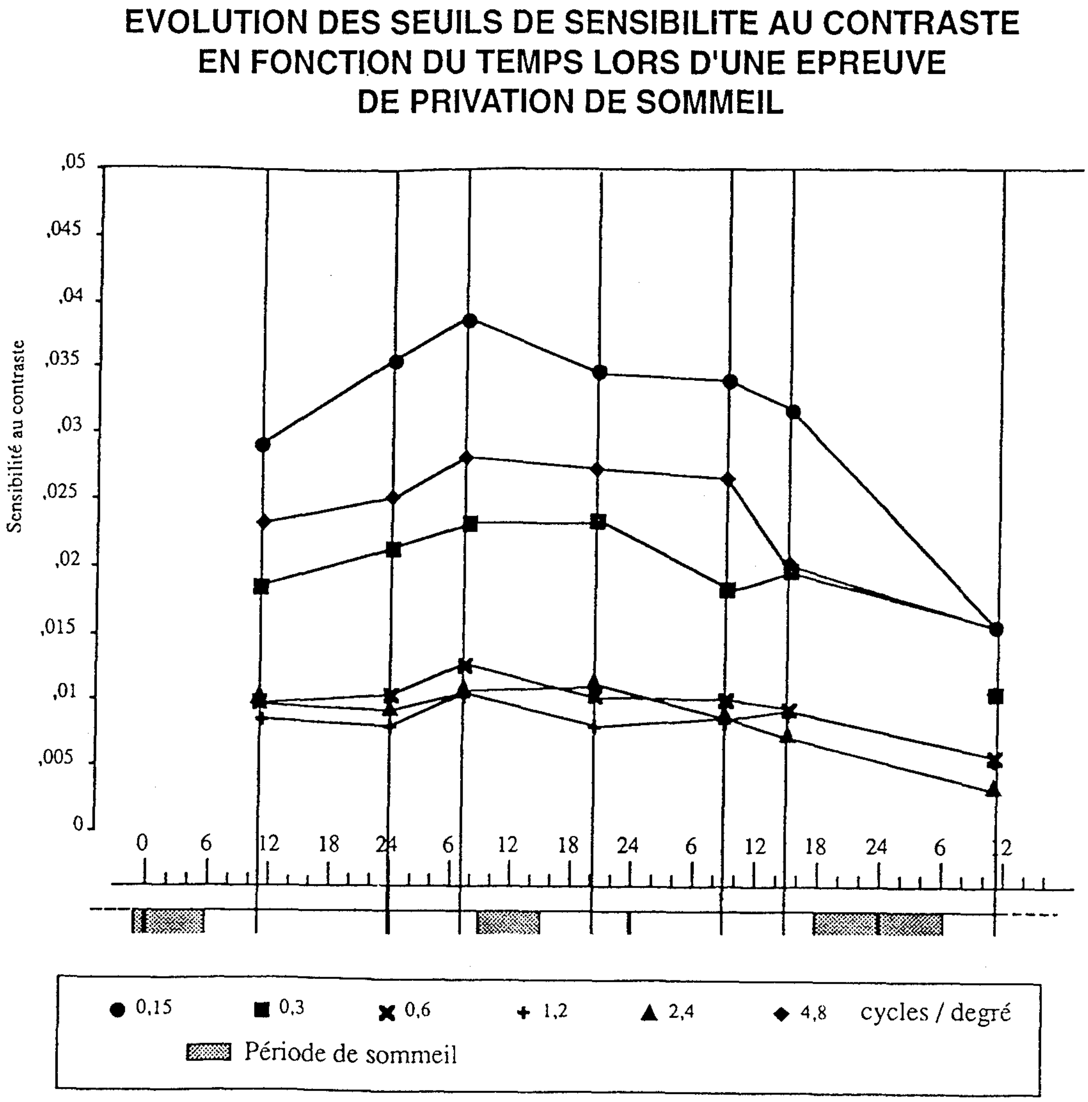

EVOLUTION DES SEUILS DE SENSIBILITE AU CONTRASTE
EN FONCTION DU TEMPS LORS D'UNE EPREUVE
DE PRIVATION DE SOMMEIL
Sensibilité au contraste
,05
,045
,04
,035
,03
,025
,02
,015
,01
,005
0
0 6 12 18 24 6 12 18 24 6 12 18 24 6 12
0,15
0,3
0,6
1,2
2,4
4,8
cycles / degré
Période de sommeil

Figure 8

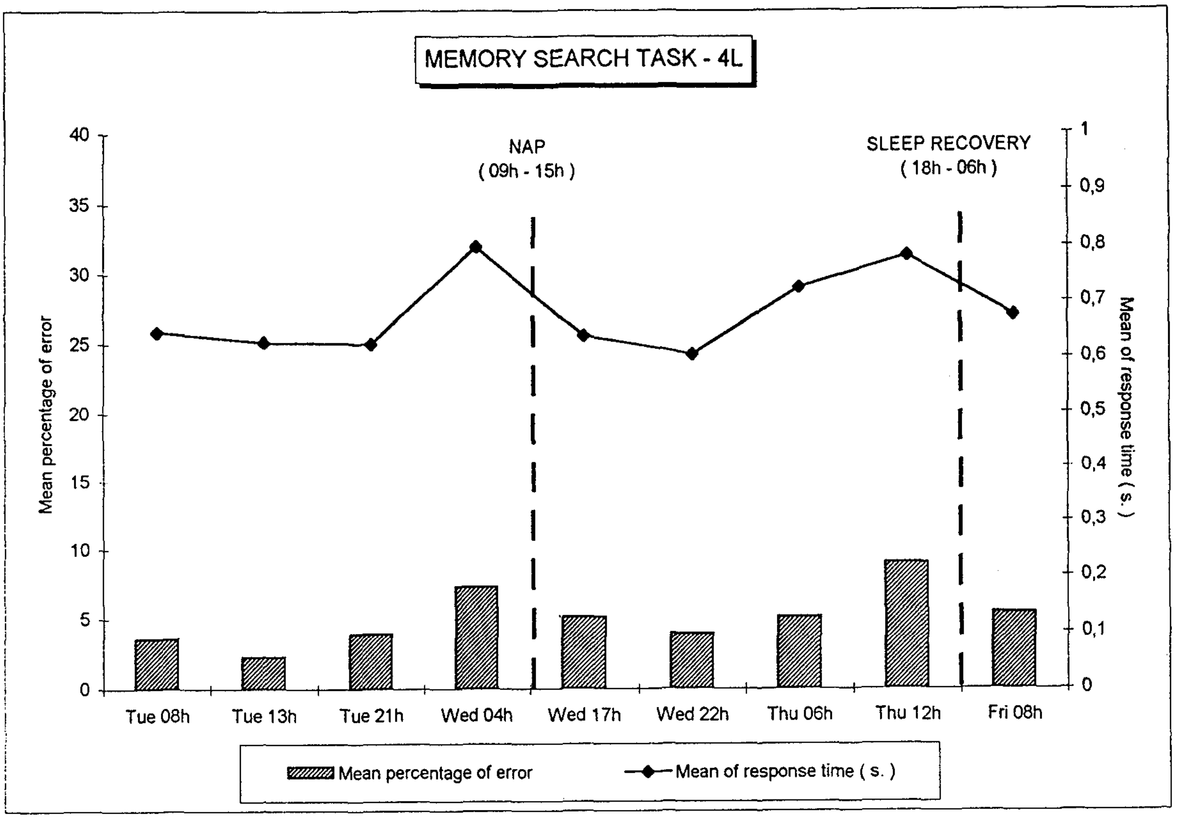
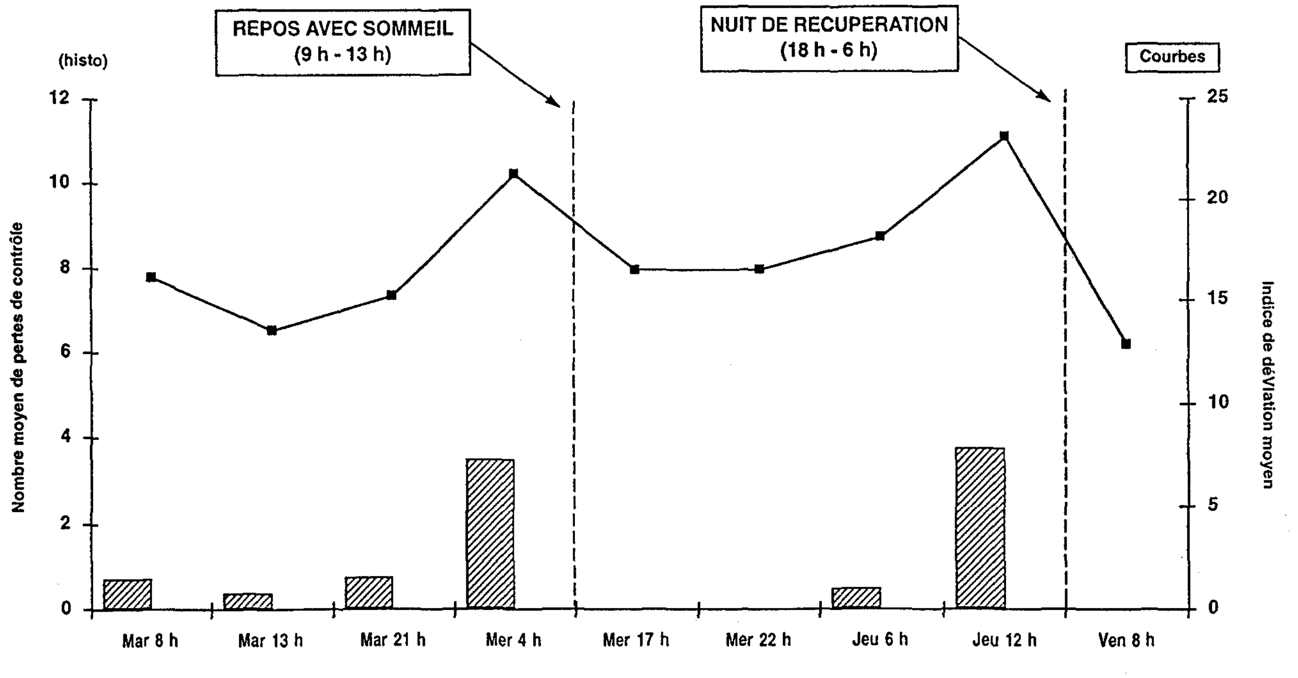


Figure 9

TACHE DE POURSUITE



Tâche de poursuite. Évolution de la performance au cours de l'expérimentation Iron Man :
(deux fois 27 heures de privation de sommeil séparées par un somme diurne de 6 heures)
D'après BATEJAT et LAGARDE (1993)

Figure 10

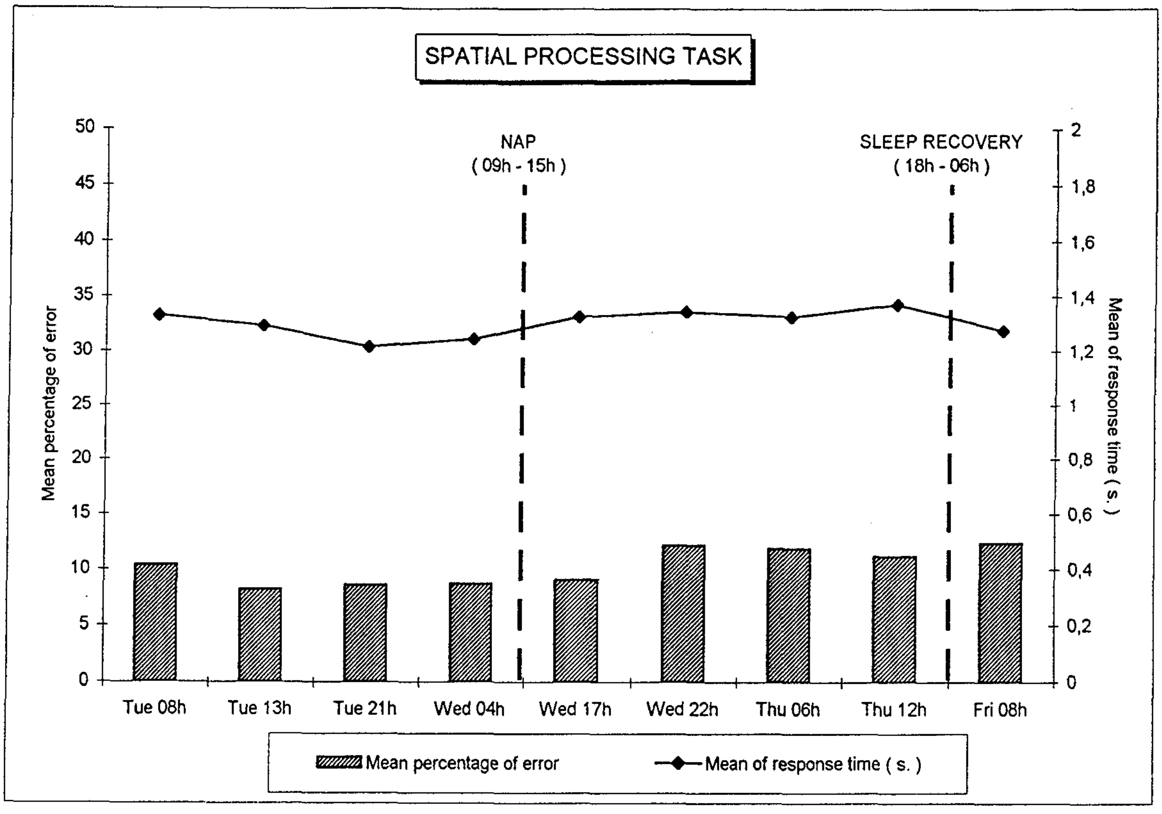


Figure 11

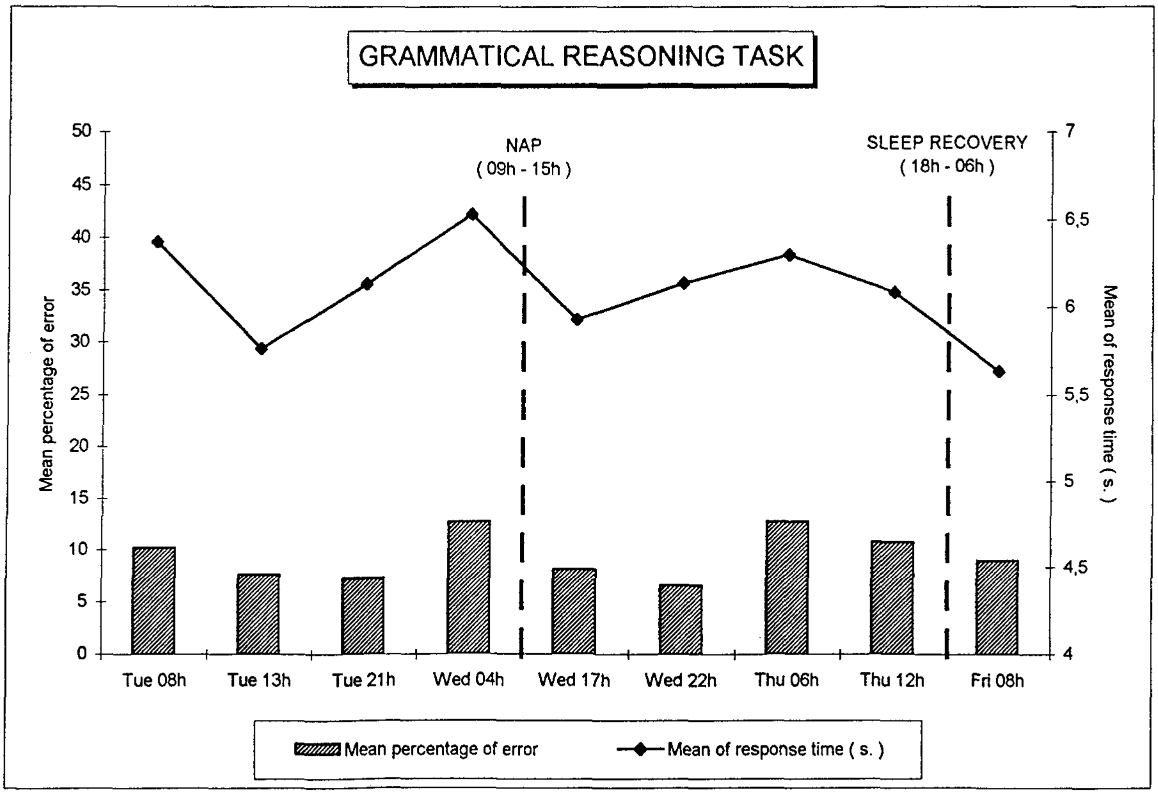


Figure 12

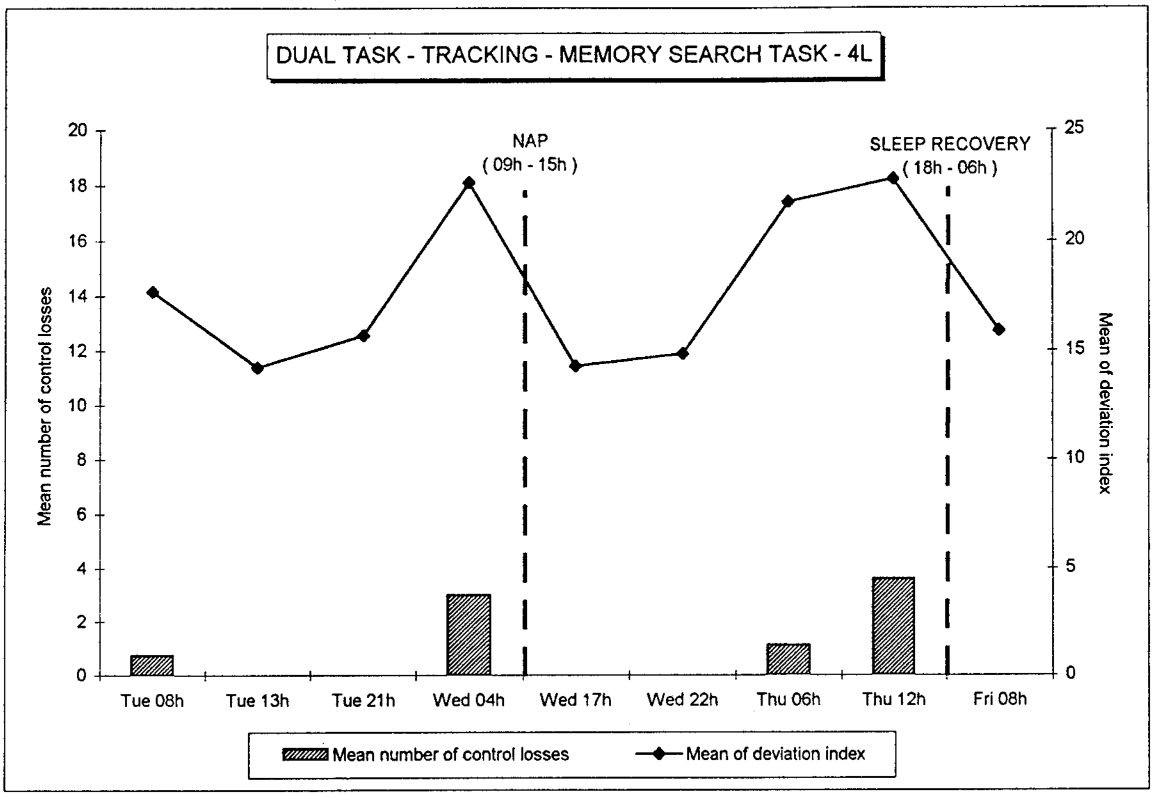

DUAL TASK - TRACKING - MEMORY SEARCH TASK - 4L
NAP
(09h - 15h)
SLEEP RECOVERY
(18h - 06h)
Mean number of control losses
Mean of deviation index
20
18
16
14
12
10
8
6
4
2
0
25
20
15
10
5
0
Tue 08h
Tue 13h
Tue 21h
Wed 04h
Wed 17h
Wed 22h
Thu 06h
Thu 12h
Fri 08h
Mean number of control losses
Mean of deviation index

Figure 13

USE OF PSYCHOSTIMULANTS IN EXTENDED FLIGHT OPERATIONS: A DESERT SHIELD EXPERIENCE

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The armed forces of most countries have used psychostimulants for centuries. Caffeine, a mild stimulant, is used nearly universally by both military and civilian populations in peacetime, but its use in the military increases during conflicts as the pace of operations expands. The widespread use and addiction to this drug is accepted as normal in most facets of life, and the stimulant effects of this drug cannot be overlooked when discussing psychostimulants. Amphetamines have been used since the 1930's for their stimulant and appetite suppressive properties. In World War II they were widely used (and abused) for their stimulant effects during military campaigns (1). During the Viet Nam (Southeast Asian) conflict the use of amphetamines was again tied to military missions, especially the pilots of both the U.S. Air Force and U.S. Army (2,3). The pilots adopted the term “Go pills” for amphetamine preparations. After that time the Air Force continued to use dextroamphetamine, in a medically controlled environment, for long overseas deployments of fighter aircraft (2). These flights were generally 8-12 hours in length and required multiple aerial refuelings enroute. Low dose amphetamines were used to maintain performance on these long boring flights. They were not used to improve performance above rested baseline; they simply kept pilots awake. The next combat use was during the raid on Libya (Operation El Dorado Canyon) in 1989 by U. S. Air Force FB-111 aircrew flying out of the United Kingdom. This mission was approximately 13 hours and little crew rest was obtained before take-off (4). During the opening night of Operation Just Cause, the invasion of Panama in 1989, dextroamphetamine was again used. F-15 fighter pilots did not get adequate sleep before flying most of the night on a long, low task mission. The majority of pilots in both of these missions found that after being awake all day and night they needed something to maintain alertness while flying during their circadian trough. Amphetamines were used by 64% of pilots who flew the long overwater deployment to the Persian Gulf (13 -17 hours) in August, 1990, and during the 40 day war (Desert Storm) in January and February, 1991 (5-7). Five milligrams of dextroamphetamine every two to four hours as needed has long been the dose used to maintain alertness in these pilots. There have been no adverse side effects reported and no known cases of subsequent illegal use or abuse.

The present study examined the use of dextroamphetamine by F-15C fighter pilots during Operation Desert Shield, the five month build up after arrival in Saudi Arabia but before Desert Storm (Persian Gulf War). These pilots were tasked with providing a continuous defensive and deterrent position in front of vulnerable high value assets, and were flown as Combat Air Patrol (CAP) missions. Airborne Warning and Control Squadron (AWACS) jets flew 24 hours a day to monitor Iraqi air activity, and F-15C aircraft flew missions to protect the AWACS and Saudi Arabia from a surprise attack. The missions were typically 4-6 hours in length and were scheduled well in advance. Additionally there were plenty of aircraft and pilots available to fly these missions. Thus, the pilots were well rested before all of these flights.

METHODS

Following their redeployment to the United States, pilots from two F-15C squadrons were asked to answer a questionnaire about their experiences during Operation Desert Shield. A

Paper presented at the Aerospace Medical Panel Symposium on “Neurological Limitations of Aircraft Operations: Human Performance Implications”, held in Köln, Germany from 9-12 October 1995, and published in CP-579.

total of 70 pilots were in the two squadrons during the deployment. Pilots who had already been transferred to another assignment, or who had left the Air Force at the time of this survey, were not contacted. Information gleaned included demographic data about each pilot, experience before the deployment, the deployment, mission profiles, and dextroamphetamine ("Go pill") use.

RESULTS

Forty five of the 70 (64%) pilots who deployed in the two squadrons responded to the questionnaire. Most of the non-responders had transferred from the squadrons before the survey was available. The demographic data are presented below.

Age: mean-30.8 years, range 25-43
Fighter experience: 780 hours, range 100-2600
Dextroamphetamine use prior to Desert Shield: Yes-11, No-34
Flight hours during Desert Shield: mean-202 hours

Of the 45 who responded, 26 (57.8%) used the "Go pills" during Desert Shield. All use occurred on CAP missions protecting AWACS and other high value assets. Almost all "Go pill" usage (96%) occurred during night missions. Only one pilot reported using a "Go pill" during the day. The pilots reported the greatest difficulty staying awake from about 0300 until dawn. Medication was never used on routine training flights flown before the war began, but these were generally less than 90 minutes in duration and had a more interesting and fun mission profile than flying CAP.

The typical Desert Shield mission profile was to take-off and fly to the assigned area and aerial refuel. These fighter pilots would then relieve the flight who had been manning the CAP. During the CAP phase the pilots flew a race track type oval that took about eight to ten minutes per lap (Fig 1). During the hot leg of the CAP the F-15C radar was used to sanitize the airspace in front of the F-15s. If any air activity was spotted by either the F-15C's or the AWACS both parties communicated this to each other. During the cold leg of the CAP the pilots listened to the communications of the pilots on the opposite leg for any activity in order to prepare for their hot leg. Actual CAP flying over the Saudi Arabian Desert was not very exciting because there was very little air activity in Iraq for the pilots to monitor. Thus, almost all laps flown around the CAP occurred with little or no radio communication. Pilots noted that the cold leg of the CAP was especially boring because there was nothing to do but wait until they could turn back onto the hot leg. Twenty-seven pilots (61%) reported falling asleep or becoming very inattentive while in the CAP. Anecdotally, this was primarily on the cold leg of the CAP. Even though there was little to do on the hot leg, apparently there was enough stimulation by working the radar and the threat of flying into hostile territory to motivate them to stay awake. This sequence continued for about 1.5 hours at which time the jets would fly a short distance to the tanker for aerial refueling. They would then reestablish the CAP formation. The typical sortie was 4-6 hours in length. This equates to two to three CAP and refueling segments before returning to base. Pilot comments were universally in favor of the performance maintenance properties of dextroamphetamine. One squadron commander stated that the availability of the "Go pills" was a "safety of flight" issue. One pilot who did not use the medication said "We should always carry them for safety, and use them when safety is in question." Another pilot said "without Go pills I would have fallen asleep maybe 10-15 times." Another commented that the dextroamphetamine "did not make you hyperactive or jittery like caffeine can. It simply kept you awake, like you feel during the day." Another pilot stated he never got the "leans" refueling in instrument flight conditions while taking "Go pills," while he almost always got the leans when not on the medication.

CONCLUSIONS

Over half of the pilots questioned used the performance medication, dextroamphetamine, during Desert Shield. It was used almost exclusively on long, low task missions at night. Individual pilots used the medication when they felt they were extremely drowsy and/or inattentive. Even the pilots who did not feel

they needed "Go pills" were glad they had them available just in case they needed them. Although caffeine is widely used by all facets of the population and maybe considered a preferable drug choice, it is not a good alternative to dextroamphetamine for fighter pilots on aerial combat missions. First, caffeine is a very weak, centrally acting stimulant (8). Additionally, caffeine produces a profound diuretic affect. This leads to further dehydration in the fighter pilot who is already working hard to maintain adequate hydration for good G tolerance for air combat. Also, caffeine has none of the anti-vestibular properties that dextroamphetamine possesses . These properties may decrease the susceptibility to disorientation or spatial illusions, as in the pilot who reported the "leans" without "Go pills."(9)

Today we are asking our fighter pilots to fly numerous, relatively long, boring missions during both day and night in places like Northern and Southern Iraq and Bosnia to maintain air superiority and oppose ground forces. Rarely is there anything for the pilots of these primarily single seat jets to do other than fly CAP. When the pilots' alertness falls to an unacceptably low level, use of a performance maintenance medication is appropriate to prevent the loss of military aircraft and personnel due to pilot drowsiness or decreased vigilance.

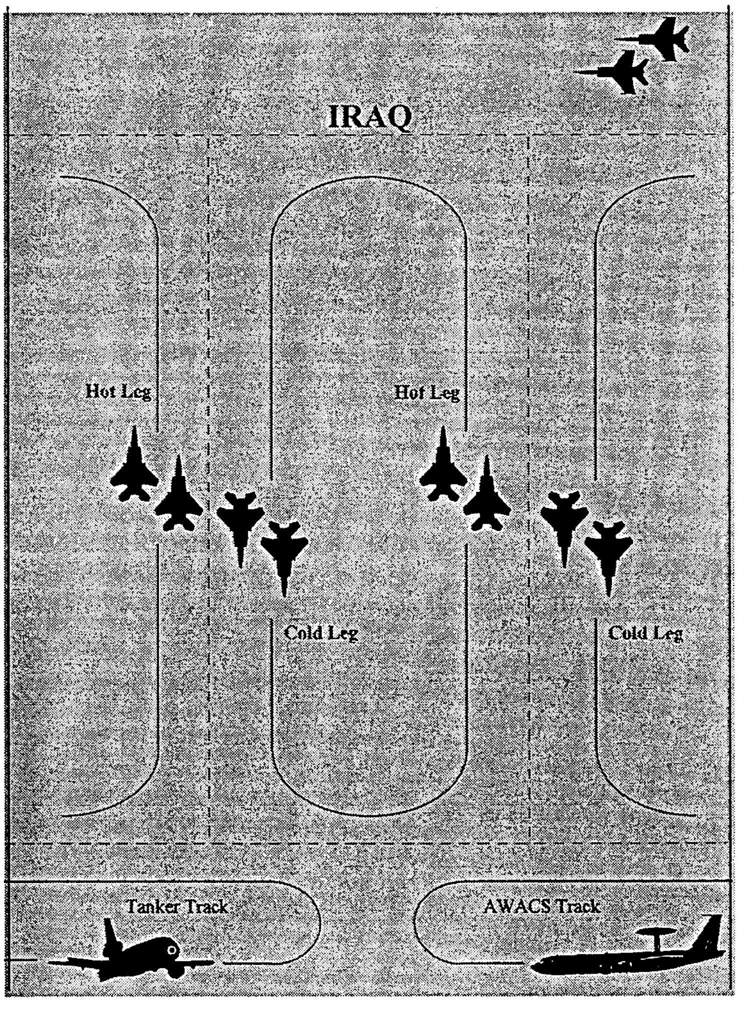

Figure 1. Typical Combat Air Patrol (CAP)

*Lt Col Kory Cornum was assigned to the 58 Fighter Squadron, 33 Fighter Wing, Eglin AFB, FL from 1988-1993 as the squadron flight surgeon. During this time he and the squadron deployed overseas numerous times and participated in Operations Just Cause, Desert Shield and Desert Storm.

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Sustaining Helicopter Pilot Alertness with Dexedrine® During Sustained Operations

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SUMMARY

Sustained operations are a tactical necessity on the modern battlefield. However, the strain on personnel from sleep deprivation and fatigue remains problematic. Effective crew work/rest policies may prevent sleep loss and subsequent performance decrements in some situations, but stimulant medications may be the only alternative for sustaining performance in unpredictable combat operations. The present study investigated the efficacy of using dextroamphetamine as a countermeasure to sleep loss during sustained operations. Twelve subjects (6 males and 6 females) were exposed to two, 40-hour periods of continuous wakefulness during which they flew a helicopter simulator and completed electroencephalographic (EEG) and mood evaluations. During the final 23 hours of one period, subjects were administered 3 separate 10-mg doses of Dexedrine® (at 0000, 0400, and 0800), and during the final hours of the other period, subjects were administered placebo. Test sessions occurred at 0100, 0500, 0900, 1300, and 1700 on both days. Results showed that flight performance was better under Dexedrine® than placebo on 7 out of 9 sets of maneuvers. The benefits from Dexedrine® were particularly apparent during the 0500 and 0900 flights when the combination of fatigue and circadian effects were most severe. Both EEG and mood evaluations were consistent with the performance effects in that Dexedrine® was found to reduce slow-wave brain activity (associated with fatigue) and improve subjective ratings of vigor, fatigue, and mental abilities. These data indicate that Dexedrine® is a viable countermeasure for sustaining the performance of both male and female pilots when operational demands prevent adequate, restorative sleep.

BACKGROUND

Different strategies have been investigated to minimize fatigue-related performance decrements in various work settings[1], but the combat situation remains problematic because it is intense and unpredictable. As Cornum[2] has pointed out, while it is desirable to control the timing and duration of sleep periods via sleep management programs, this approach often is not feasible in the operational setting. One illustration of this fact was offered by recent research which suggested that despite commanders' best efforts to properly manage crew rest in the combat environment, sleep deprivation was a problem for several Army pilots during Desert Storm even though the combat period was short.[3] In addition, it has been reported that Air Force F-15C pilots suffered significant fatigue and circadian disruptions when flying combat air patrol missions over Iraq.[2]

When operational constraints prevent the use of behavioral strategies for the alleviation of aircrew fatigue, pharmacological countermeasures (stimulants) may be the only option for maintaining aviator performance. Of the pharmacological compounds available in the United States, amphetamines offer the greatest potential for counteracting performance decrements attributable to sustained operations.[4] Dexedrine® has been the stimulant of choice in several studies and in the operational environment.

Senechal[5] reported that EF-111A Raven jet crews who were administered 5 mg Dexedrine® during an Air Force strike on Libya in April of 1986 experienced positive effects in terms of overcoming the fatigue of the mission itself and the sleep deprivation which occurred during earlier preparation for the mission. There were no in-flight or landing problems, and all of these electronic-jamming aircraft returned safely to base. Cornum[6] reported that dextroamphetamine also was used with 35 F-15C pilots who were flying combat air patrol missions during Operation Desert Shield/Storm. These pilots were not only flying long missions (6-11 hours), but they were sleep deprived and suffering from circadian desynchronosis as well. To counteract potentially lethal performance decrements, the pilots were issued 5-6 dextroamphetamine tablets (5 mg) at the beginning of flights and were told to self-administer one tablet every 2-4 hours as needed to maintain alertness until landing. The aviators reported clear benefit from the drug, and the unit commander ultimately concluded that dextroamphetamine administration contributed significantly to the safety of operations. There were no reported adverse effects, even in personnel who took 10 mg at a time, and no aviators reported a need to continue the drug once proper work/sleep schedules were reinstated. Emonson and Vanderbeek[7] indicated that Air Force pilots effectively used dextroamphetamine during Operation Desert Storm to maintain acceptable performance during continuous and sustained missions. The medication was found to be both safe and beneficial in terms of overcoming fatigue without producing unwanted side effects.

Thus, there are several anecdotal reports suggesting Dexedrine® has been useful in operational environments; however, controlled laboratory studies with aviators are virtually nonexistent. The present study was conducted to address this

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lack of experimental data and to verify the effectiveness of Dexedrine® for use in a sustained operations context in both male and female aviators.

METHODS

Subjects

Six female UH-60 pilots (with a mean age of 29.5 years) and six male UH-60 pilots (with a mean age of 27.8 years) participated after signing consent forms. The males were tested in 1993, and the females were tested in 1994 (the data from the 2 studies were combined for this report). Subjects were not permitted to consume caffeinated beverages, fruit, fruit juice (with the exception of orange juice administered at dosing times) or any medication (other than acetaminophen, ibuprofen, birth-control pills, or Dexedrine®) during the protocol. Subjects were asked to reduce or eliminate caffeine consumption beginning several days prior to the study (although none of the subjects normally used substantial amounts of caffeine). Only one of the subjects was a cigarette smoker. The average amount of flight experience for the females was 748 hours (ranging from 400-1200 hours), and the average amount for the males was 723 hours (ranging from 140-1500 hours). The average weights were 133.8 for the females and 166.0 for the males.

Apparatus

Drug dosing. At each dose interval, subjects were administered two orange gelatin capsules (placebo or Dexedrine®) with approximately eight ounces of orange juice. Each of the placebo capsules was filled with lactose, and each of the Dexedrine® capsules contained 1, 5-mg Dexedrine® tablet placed in the lactose powder.

UH-60 flight simulator. Flights were conducted in a UH-60 helicopter simulator with a 6-degree-of-motion base and a full-visual cockpit in which the visual display was set for daytime flight. Flight data (heading, airspeed, altitude, etc.) were acquired on a Digital Equipment Corporation VAX 11/780. The acquired data were converted to composite flight scores using specialized software routines.[8]

EEG evaluations. The electroencephalographic (EEG) evaluations were performed with a Cadwell Spectrum 32. Twenty-one channels of EEG data were collected and stored on optical disk for subsequent analysis, although only a subset of these data were analyzed for this report. The low filter was set at 0.53 Hz, the high filter was set at 70 Hz, and the 60-Hz notch filter was used. Subjects were outfitted with 25 Grass E5SH silver cup electrodes which were affixed to the scalp with collodion for the duration of the study (6 days). Active EEG channels were referenced to linked mastoids.

Profile of mood states. Subjective evaluations of changes in mood were made with the Profile of Mood States (POMS).[9] This 65-item paper and pencil test measures affect or mood on 6 scales: 1) tension-anxiety, 2) depression-dejection, 3) anger-hostility, 4) vigor-activity, 5) fatigue-inertia, and 6) confusion-bewilderment.

Procedure

Each subject completed several simulator flights, EEG evaluations, and POMS questionnaires under Dexedrine® and placebo. The dose-administration schedule was fully counterbalanced and double blind.

Flight performance. The flight performance evaluations required subjects to perform a variety of standard flight maneuvers. The first part of each flight consisted of hovers and tactical navigation in which subjects used visual cues, global positioning system (GPS) information, and time information to correctly navigate a prescribed course. The second part consisted of nontactical, upper-airwork which required subjects to perform instrument maneuvers.

The low-level navigation portion of the profile began with four hovers. There was a stationary 10-foot hover, a 10-foot hovering turn (360°), a stationary 40-foot hover, and a 40-foot hovering turn (360°). These maneuvers were followed by flight to five different check points using the GPS.

During the stationary hovers, subjects were required to maintain precise control over altitude and heading, whereas during the hovering turns subjects focused on altitude control. During the low-level navigation, subjects were required to maintain control of altitude, slip, and roll while minimizing the deviation between their heading and the bearing to the next checkpoint.

The upper-airwork consisted of maneuvers which the subjects flew in a specific order during each flight. The first group of maneuvers was flown with the automatic flight control system (AFCS) trim engaged (the normal mode for the UH-60), and the second group was flown with the AFCS trim turned off. The AFCS trim system enhances the stability and handling qualities of the aircraft/simulator, and when the AFCS is turned off, accurate flight control becomes much more difficult.

There were 15 maneuvers in the upper-airwork profile. There were four straight-and-levels (one with AFCS off), two left standard-rate turns (one with AFCS off), three right standard-rate turns (one with AFCS off), two standard-rate climbs (both with AFCS on), three standard-rate descents (all with AFCS off), and one left descending turn (with AFCS off).

During each maneuver, the subject was required to maintain precise control over specific flight parameters (i.e., heading, altitude, airspeed, etc.) which varied across maneuvers. For

instance, heading control was evaluated during straight-and-level flight, but not during turns. Scores which reflected how well the subject flew each maneuver were calculated in two steps. First, the control scores for the parameters relevant to each maneuver were determined using the limits presented in Table 1. Thus, if a subject never deviated from the assigned heading by more than 1 degree, he/she earned a score of 100, whereas larger deviations produced lower scores. Second, the scores from each individual parameter were averaged into a single composite score. Thus, if a subject scored 100 on heading, 85 on altitude, and 90 on airspeed, the composite score would have been 91.7.

Table 1. Scoring bands for flight performance data.

	Maximum deviations for scores of:					
Measure (units)	100	80	60	40	20	0
Heading (degrees)	1.0	2.0	4.0	8.0	16.0 >	16.0
Altitude (feet)	8.8	17.5	35.0	70.0	140.0 >	140.0
Airspeed (knots)	1.3	2.5	5.0	10.0	20.0 >	20.0
Slip (ball widths)	0.0	0.1	0.2	0.4	0.8 >	0.8
Roll (degrees)	0.8	1.5	3.0	6.0	12.0 >	12.0
Vert. Speed (feet/m)	10.0	20.0	40.0	80.0	160.0 >	160.0
Turn Rate (degrees/s)	0.3	0.5	1.0	2.0	4.0 >	4.0

EEG. Each EEG session required that subjects sit quietly with eyes open for 1.5 m followed by 1.5 m of eyes closed. After the resting EEG, subjects were given a series of evoked potential tasks not reported here. Three relatively artifact-free, 2.5-second epochs of EEG from each session were used to determine the absolute power values for each of four bands. The results were averaged to produce one set of power values for each electrode site under eyes closed and eyes open (separately). Unfortunately the theta and alpha bands were changed slightly between the time the females were tested and the time the males were tested. For the females, the bands were: delta (1.0-3.0 Hz), theta (3.0-8.0 Hz), alpha (8.0-13.0 Hz), and beta (13.0-20.0 Hz). For the males they were: delta (1.0-3.0 Hz), theta (3.0-7.5 Hz), alpha (7.5-13.0 Hz), and beta (13.0-20.0 Hz).

Profile of Mood States. For each POMS, subjects indicated how well each of 65 words which described mood states described the way he/she presently was feeling. This test was hand-scored to yield scores on six dimensions.

Test schedule. Subjects arrived at approximately 1800 on Sunday, at which point the study was explained, the informed consent agreement was signed, and the medical evaluation was conducted. Subjects with past psychiatric or cardiac disorder, allergic reactions to aspirin, a history of sleep disturbances, or any current significant illness would have been rejected, but none of these problems were found. After the physical examination, EEG electrodes were attached according to the International 10-20 guide.

On Monday morning, the subject was given a 2.5 mg dextroamphetamine test dose followed by 3 training sessions consisting of simulator flights, EEG tests, and POMS administrations. At 2100 hours, the aviator participated in physical exercise, showered, and then went to sleep. On Tuesday, there were three baseline sessions, each of which included the simulator flight, EEG, and POMS. At the end of Tuesday, the aviator was not allowed to go to sleep, but was given his/her first drug/placebo dose at 0000 hours on Wednesday morning followed by subsequent doses at 0400 and 0800. Test sessions began 1 hour after each drug/placebo administration (for the first 3 sessions), and there were 2 additional nondrug sessions as well for a total of 5 equally-spaced sessions (at 0100, 0500, 0900, 1300, and 1700). On Thursday, after 8 hours of recovery sleep, the subject repeated the same schedule which was used on Tuesday, and afterwards, he/she was given the first dose in the second series of drug/placebo doses at 0000 on Friday morning. On Friday, the subject repeated the Wednesday schedule, beginning the first simulator flight of the day at 0100 and completing the other sessions at 4-hour intervals until 2000. At 2300 hours, he/she retired for the day. On Saturday, the subject was released.

RESULTS

Flight performance.

BMDP 4V[10] was used to conduct a series of analyses of variance (ANOVAs) on the composite flight scores from each maneuver in the flight profile. There was one grouping factor and three within-subjects factors. The grouping factor was gender (males, females), and the first two within-subjects factors for each maneuver were drug (placebo, Dexedrine®) and session (0100, 0500, 0900, 1300, and 1700). Maneuvers which were flown more than once during each flight profile included a third factor designated iteration. There were two iterations of stationary hovers, two iterations of hovering turns, four navigation legs, four straight-and-levels, three right-standard-rate turns and descents, and two left-standard-rate turns and climbs. Significant main effects and interactions from these ANOVAs were followed by appropriate posthoc analyses consisting of simple effects and/or contrasts to pinpoint the location of noteworthy differences.

Hovers. The ANOVA (gender x drug x session x iteration) on composite altitude and heading control scores during the 10- and 40-foot stationary hovers indicated there was a significant hover-by-gender interaction ($F(1,10)=10.82$, $p=.0082$), but no other interactions or main effects. Analyses of simple effects

indicated that the males were more accurate than the females during both the 10- and 40-foot hovers (p<.05), but the difference was most noticeable at the lower altitude. The ANOVA on the composite scores (based on altitude control) during the hovering turns showed there was only a main effect attributable to iteration (F(1,10)=206.99, p<.0001). This was because performance on the 10-foot hover was better than performance on the 40-foot hover.

Low-level navigation. The ANOVA (gender x drug x session x navigation leg) on the composite heading, altitude, slip, and roll control scores during the low-level navigation indicated there was an interaction between gender and navigation leg (F(3,30)=5.66, p=.0034), an overall difference among the navigation legs (F(3,30)=62.29, p<.0001), and an effect attributable to drug condition (F(1,10)=24.12, p=.0006). The interaction was because of slight differences in the performance patterns of males and females. In both groups, scores during the third leg were worse than scores on all the others, and scores on the second leg were better than scores on the first and third; however, only in the males was the second leg significantly better than the fourth. The overall difference among the navigation legs (a main effect) was consistent with what was found in the interaction--scores from the third leg were the lowest and scores from the second leg were the highest. The difference between the drug conditions was due to better performance under Dexedrine® than placebo (the mean scores were 76 versus 73).

Straight and levels. The ANOVA on the composite of heading, airspeed, altitude, slip, and roll scores during the four straight-and-level (SL) maneuvers (with no AFCS on SL4) indicated several effects. There was an interaction between drug and SL (F(3,30)=9.10, p=.0002) which was due to poorer performance under placebo than Dexedrine® at every iteration except the third (p<.05). Also, the difference between Dexedrine® and placebo was most pronounced at SL 4 when the AFCS was not engaged. There was an interaction between drug and session (F(4,40)=5.5.4, p=.0012) which was because of higher scores under Dexedrine® than placebo at every flight (p<.05) with the exception of the 0100 (see figure 1). Besides these interactions, there were main effects on every factor except gender. There was a main effect on iteration (F(3,30)=26.81, p<.0001) which was due to the fact that SL1 was better than all the other SLs, while SL4 (without AFCS) was worse than the others (p<.05). There was a main effect on the session factor (F(4,40)=4.06, p=.0074) which was due to an overall decline in performance from the first flight of the day to the last (p<.05). Also, there was a main effect on the drug factor (F(1,10)=19.53, p=.0013) which was attributable to higher scores under Dexedrine® than placebo (the mean scores were 87 versus 83).

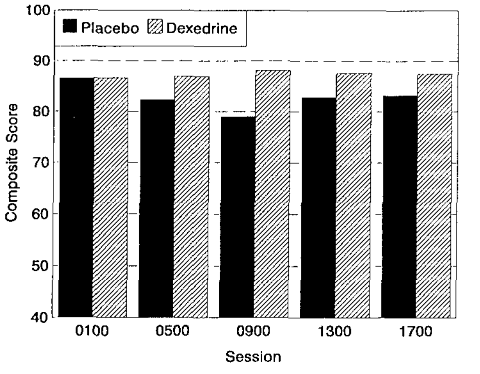

Figure 1. Drug and session effects on straight-and-level performance.

Climbs. The two climbs (flown with AFCS engaged) were evaluated in terms of how well subjects controlled heading, airspeed, slip, roll, and rate of climb. The ANOVA (gender x drug x session x iteration) indicated a drug-by-session interaction (F(4,40)=3.63, p=.0130), an iteration main effect (F(1,10)=38.98, p=.0001), and a drug main effect (F(1,10)=4.86, p=.0521). The drug-by-session interaction was due to significantly better performance under Dexedrine® than placebo at 0500 and 0900 (p<.05) while there were no differences at 0100, 1300, or 1700 (see figure 2). The iteration effect was because of better performance on the first climb than the second. The drug effect was because of a higher overall flight scores under Dexedrine® than placebo (the mean scores were 73 versus 70).

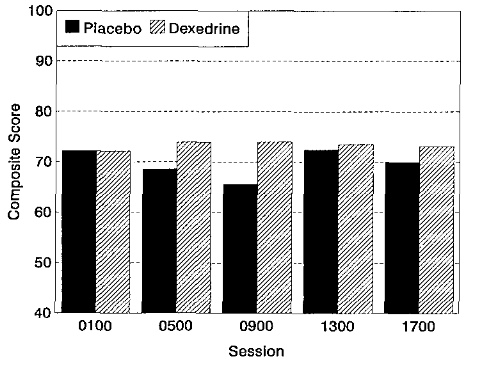

Figure 2. Effects of drug and session on climb scores.

Left standard-rate turns. The four-way ANOVA on the two left standard-rate turns (with AFCS and without AFCS) showed several effects on the composite scores from turn rate, altitude,

airspeed, slip, and roll control. There was a drug-by-iteration interaction ($F(1,10)=6.15$, $p=.0325$) which was due to significantly better performance under Dexedrine® versus placebo only on the second turn, flown without the AFCS ($p<.05$). There was a drug-by-session interaction ($F(4,40)=2.85$, $p=.0360$) which was due to the fact that Dexedrine® was associated with better performance than placebo at 0500 and 0900 ($p<.05$), but not at the other flights of the day (see figure 3). There were also main effects on the iteration factor ($F(1,10)=99.19$, $p<.0001$), the session factor ($F(4,40)=2.72$, $p=.0427$), and the drug factor ($F(1,10)=8.21$, $p=.0168$). The iteration effect was due to better performance on the first turn (with the AFCS) than the second turn (without the AFCS). The session effect was because overall performance declined from 0100 to 0900 and then improved from 0900 to 1300 ($p<.05$). The drug effect was due to better performance under Dexedrine® than placebo (the mean scores were 73 versus 69).

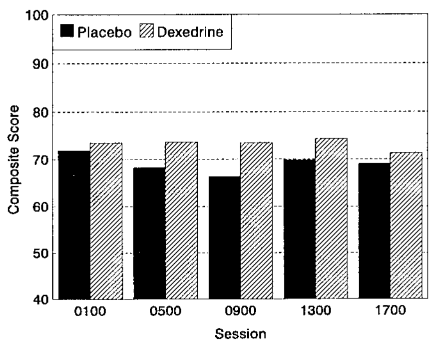

Figure 3. Effects of drug and session on left standard-rate turns.

Descents. The three descents(flown without the AFCS engaged) were evaluated in terms of how well subjects controlled heading, airspeed, slip, roll, and rate of descent. The ANOVA on the composite scores revealed several main effects and interactions. There was a three-way interaction among gender, drug, and descent ($F(2,20)=3.88$, $p=.0377$) which was attributable to the fact that there was an interaction between drug and descent in the males ($p<.05$), but not the females. Further analyses showed that within the males there was better performance on the first descent than on the third descent under placebo ($p<.05$), while there were no differences among the three descents under Dexedrine®. This finding was consistent with the two-way, drug-by-descent interaction ($F(2,20)=3.72$, $p=.0422$) which was due to better performance on the first than the third descent only under the placebo condition. Also, while Dexedrine® produced significantly better performance than placebo on every iteration, the difference was largest during the last descent (the longest of the three). This effect is depicted in figure 4. There also was a drug-by-session interaction ($F(4,40)=7.69$, $p=.0001$). This was because Dexedrine® produced higher flight scores than placebo at every session with the exception of the first one of the day where there was no difference. Main effects were found for both session ($F(4,40)=7.69$, $p=.0005$) and drug ($F(1,10)=18.13$, $p=.0017$). The session effect was attributable to better overall performance at 0100 than at 0500, 0900, and 1700 ($p<.05$). In addition, performance was better at 1300 than it was at 0900. The drug main effect was because Dexedrine® was associated with better flight performance than placebo (the mean scores were 65 versus 58).

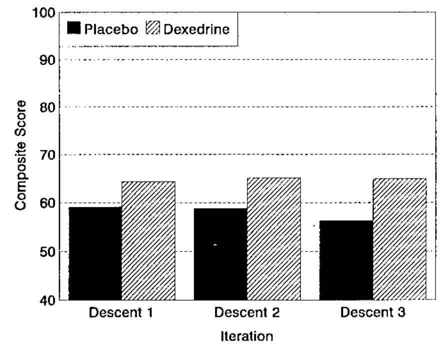

Figure 4. Effect of drug and iteration on descent scores.

Right standard-rate turns. During the three right standard-rate turns (RSRTs) subjects focused on the control of turn rate, altitude, airspeed, slip, and roll. The first and second RSRTs were flown with the AFCS trim engaged, and the third RSRT was flown with the AFCS trim off. The four-way ANOVA (gender x drug x session x iteration) indicated there was an interaction between session and iteration ($F(8,80)=2.16$, $p=.0390$). This was because while scores on the second turn were better than scores on the third turn at every session; the first turn was better than the third only at 0500, 0900, and 1300; while the first was poorer than the second only at 0100, 1300, and 1700. In addition to this interaction, there were main effects attributable to iteration ($F(2,20)=24.31$, $p<.0001$), session ($F(4,40)=2.96$, $p=.0312$), and drug ($F(1,10)=17.02$, $p=.0021$). The iteration effect was due to the fact that overall performance increased from the first to the second turn, and decreased from the second to the third turn; however, performance on the third turn was also lower than performance on the first ($p<.05$). The session effect was because performance dropped between 0100 and 0900, while it increased from 0900 to 1700 ($p<.05$). The drug effect was because Dexedrine® produced better overall performance than placebo (the mean scores were 77 versus 71).

Left descending turn. The left descending turn, conducted with the AFCS off, was scored in terms of how well subjects maintained the correct rate of turn, airspeed, slip, roll, and rate of descent. Analysis of the composite scores from this

maneuver indicated there was a gender-by-session effect (F(4,40)=3.05, p=.0276) which was due to the fact that males performed better than females at the 0100 flight (p<.05), but there were no differences at the other flights of the day. There also was an overall session main effect (F(4,40)=3.18, p=.0232). This was because flight scores were higher at 0100 than at 0500, 0900, and 1300; and lower at 1700 than at 0500, 0900, and 1300 (p<.05). There was a drug main effect (F(1,10)=20.17, p=.0012) which was due to better performance under Dexedrine® than placebo (the mean scores were 57 versus 50).

Electroencephalographic data

Absolute power values from the resting EEGs were analyzed with ANOVA to determine the effects of gender (male, female), drug (placebo, Dexedrine), session (0220, 0620, 1020, 1420, and 1820), and eyes (eyes-closed, eyes-open). Data from midline electrodes were examined. One of the male subjects was excluded from the analysis due to excessive recording artifacts.

Note that these analyses are complicated by the fact there were modifications of the theta and alpha definitions between the time the males and the females were tested. The definitions for theta and alpha bands for the males were: theta (3.0-7.5) and alpha (7.5-13.0); whereas these two bands in the females were: theta (3.0-8.0) and alpha (8.0-13.0). Thus, while conclusions about drug, session, and eyes effects on theta and alpha are only minimally affected, findings involving the grouping factor (gender) are confounded.

Delta activity. The ANOVA on absolute delta revealed a drug-by-session-by-gender interaction at Oz (F(4,36)=2.74, p=.0433) which was due to a drug-by-gender effect at 1420 (p<.05), but not at the other sessions. Further analysis revealed that at 1420, there was more delta activity under placebo versus Dexedrine® in the females (p<.05), while a similar effect did not occur in the males. Another three-way interaction, drug-by-eyes-by-gender, was found at Cz (F(1,9)=6.16, p=.0349). This was because of a drug-by-eyes interaction only in the males (p<.05) which was due to more delta activity under placebo versus Dexedrine® under eyes closed, but not eyes open. There was a two-way interaction between drug and gender at Oz (F(1,9)=7.40, p=.0236) which was due to greater amounts of delta under placebo than Dexedrine® in the females (p<.05), but not the males. Drug-by-eyes interactions were found at Fz (F(1,9)=7.29, p=.0244), Cz (F(1,9)=22.87, p=.0010), and Pz (F(1,9)=6.63, p=.0300) where there was a difference between placebo and Dexedrine® at eyes closed (p<.05), but not at eyes opened (see figure 5). Examination of mean delta power at each electrode indicated there was more delta under placebo as opposed to Dexedrine® at every recording site. There were main effects on the drug, session, and eyes factors. More delta activity was present under placebo than Dexedrine® at Fz (F(1,9)=46.21, p=.0001), Cz (F(1,9)=30.24, p=.0004), Pz (F(1,9)=14.02, p=.0046), and Oz (F(1,9)=12.08, p=.0070). These effects are depicted in figure 6. A session effect was found only at Oz (F(4,36)=3.16, p=.0251), and this was due to less delta at 0220 in comparison to 1020, 1420, and 1820 (p<.05). Also, there was more delta activity during eyes closed than during eyes opened at Fz (F(1,9)=40.35, p=.0001), Cz (F(1,9)=32.87, p=.0003), Pz (F(1,9)=22.03, p=.0011), and Oz (F(1,9)=16.27, p=.0030).

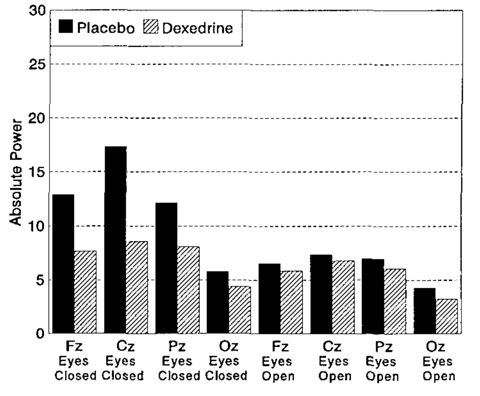

Figure 5. Effects of drug and eye closure on EEG delta activity.

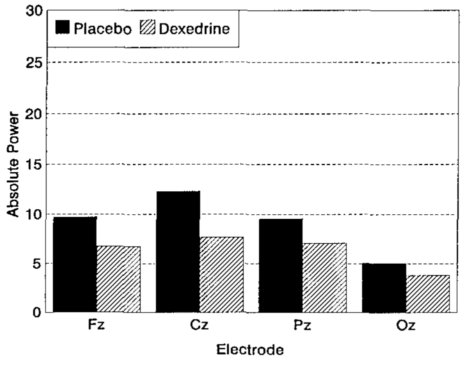

Figure 6. Main effects of Dexedrine® versus placebo on EEG delta activity.

Theta. There was a drug-by-session-by-gender interaction at Oz (F(4,36)=2.61, p=.0514) which analysis of simple effects showed was due to a drug-by-gender interaction only at 1420 (p<.05). Further analysis revealed there was more theta activity under placebo than Dexedrine® at this time only in the females (p<.05). There were also several two-way interactions. There was a drug-by-gender interaction at Oz (F(1,9)=8.01, p=.0197) which was due to an increase in theta under placebo versus Dexedrine® in the females (p<.05), while a similar effect was not observed in the males. Drug-by-eyes interactions were found at Cz (F(1,9)=9.21, p=.0141) and Pz (F(1,9)=4.83,

p=.0556). In both cases, there was significantly more theta under placebo than Dexedrine® (p<.05); however, the difference was larger at eyes closed than eyes opened (see figure 7). Also, there were main effects on the drug, session, and eyes factors. More overall theta activity was present under placebo than Dexedrine® at Fz (F(1,9)=6.48, p=.0314), Cz (F(1,9)=16.46, p=.0029), Pz (F(1,9)=15.98, p=.0031), and Oz (F(1,9)=18.48, p=.0020). These are depicted in figure 8. In addition, there was an overall increase in the amount of theta as a function of time of day at Fz (F(4,36)=4.32, p=.0059) and Oz (F(4,36)=2.95, p=.0333). Contrasts for this session effect showed there was less theta at 0220 in comparison to every other session at Fz (p<.05) and a tendency towards less theta at 0220 in comparison to every other session at Oz (p values ranged from .06 to .10). Lastly, there was more theta activity under eyes closed than eyes open at Fz (F(1,9)=23.15, p=.0010), Cz (F(1,9)=29.73, p=.0004), Pz (F(1,9)=21.50, p=.0012), and Oz (F(1,9)=12.22, p=.0068).

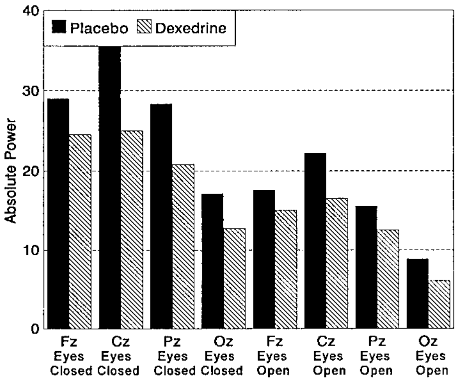

Figure 7. Effects of drug and eye closure on EEG theta activity.

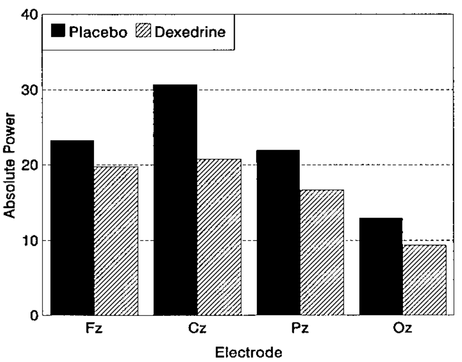

Figure 8. Main effects of Dexedrine® versus placebo on EEG theta activity.

Alpha. The ANOVA on alpha revealed several two-way interactions. There were drug-by-eyes interactions at Fz (F(1,9)=9.59, p=.0128) and Cz (F(1,9)=6.43, p=.0320) which was due to more alpha activity under Dexedrine® than placebo during eyes closed (p<.05), but not during eyes opened (see figure 9). Session-by-eyes interactions were found at Fz (F(4,36)=4.15, p=.0073), Cz (F(4,36)=3.18, p=.0245), and Oz (F(4,36)=3.05, p=.0289). These were because mean alpha power was greater under eyes closed than eyes open at every session throughout the day (p<.05) with the exception of the one at 1820. Also, as expected, there was a main effect on the eyes factor due to more alpha activity under eyes closed than eyes open at Fz (F(1,9)=12.93, p=.0058), Cz (F(1,9)=20.95, p=.0013), Pz (F(1,9)=6.79, p=.0285), and Oz (F(1,9)=10.78, p=.0095).

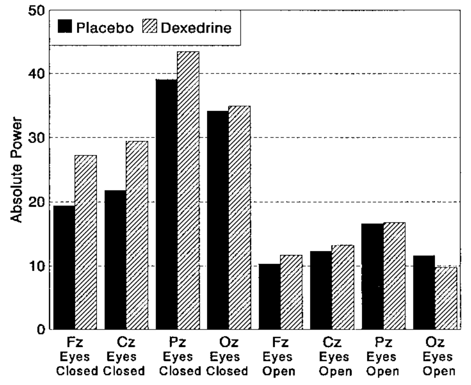

Figure 9. Effects of drug and eye closure on EEG alpha activity.

Beta. The analysis of beta activity indicated a drug-by-session-by-eyes interaction at Cz (F(4,36)=3.05, p=.0290) where there was a tendency towards a drug-by-session interaction only at eyes closed (p=.09); however, this was not significant. Further analysis revealed there was more beta activity under placebo versus Dexedrine® at eyes closed only at 1820 (p<.05). There was a drug-by-gender interaction found at Oz (F(1,9)=7.65, p=.0219). This was due to an overall increase in beta under placebo versus Dexedrine® in the females (p<.05), but not in the males. In addition, there was a session-by-eyes interaction at Fz (F(4,36)=3.12, p=.0265) which was attributable to a difference among sessions at eyes open (p<.05), but not at eyes closed. Further analysis of the amount of beta present during eyes opened indicated an increase from 0220 to 1020, and from 0620 to 1020, while there was a decrease from 1020 to 1420 (p<.05). There was a gender main effect at Oz (F(1,9)=8.26, p=.0184) which was due to more beta in the females than in the males. There were main effects on the eyes factor at Fz (F(1,9)=19.21, p=.0018), Cz (F(1,9)=38.49, p=.0002), Pz (F(1,9)=20.39, p=.0015), and Oz (F(1,9)=10.47, p=.0102), all of which were due to more beta under eyes closed than eyes opened.

Profile of Mood States

Each of the six scales from the Profile of Mood States (POMS) was analyzed with a three-way analysis of variance (ANOVA). The grouping factor was gender (male, female) and the repeated measures factors were drug (Dexedrine®, placebo) and session (0340, 0740, 1140, 1540, 1940, and 2225).

Anger-hostility. The analysis indicated an interaction between gender and drug on the anger-hostility scale ($F(1,10)=5.10$, $p=.0475$). Although it appeared this effect was due to a tendency toward higher scores under placebo versus Dexedrine® only in the males, post hoc analysis revealed there were no significant differences among the means ($p>.05$). There was however, a drug main effect ($F(1,10)=9.57$, $p=.0114$) which revealed higher overall anger-hostility scores under placebo than under Dexedrine®.

Tension-anxiety. A main effect for gender was found for the tension-anxiety scale ($F(1,10)=13.17$, $p=.0046$). The males had higher scores than the females (the means were 7.89 and 3.01 respectively). There was also a main effect for session ($F(5,50)=5.68$, $p=.0003$). Contrasts indicated this was due to a steady decrease in tension-anxiety scores as the day progressed regardless of the dose condition. The scores were higher at 0340 than at 2225, higher at 0740 than at 1940 or 2225, higher at 1140 than 2225, higher at 1540 than 1940 or 2225, and higher at 1940 than 2225 ($p<.05$). There were no drug effects on tension-anxiety scores.

Vigor-activity. There was a two-way interaction between drug and session for the vigor-activity scale ($F(5,50)=11.70$, $p<.0001$). This was due to higher vigor-activity scores under Dexedrine® than placebo at every testing session with the exception of 1940 ($p<.05$). Examined another way, there was a steady decrease in vigor-activity during the Dexedrine® day that did not occur during the placebo day (see figure 10). Contrasts among the means during the Dexedrine® day indicated higher vigor-activity scores at 0340 than at any of the other times, higher scores at 0740 than 1540, 1940, or 2225, higher scores at 1140 than at 1540, 1940, or 2225, and higher scores at 1540 than at 2225 ($p<.05$). There was a session main effect ($F(5,50)=5.43$, $p=.0005$) which was generally consistent with the interaction reported above. Contrasts indicated that, with the dose conditions collapsed, the scores were higher at 0340 than at 0740, 1140, 1540, 1940, and 2225, and higher at 1140 than at 2225 ($p<.05$). There also was an overall drug main effect on vigor-activity scores ($F(1,10)=20.68$, $p=.0011$) as well. This was attributable to higher scores under Dexedrine® than placebo.

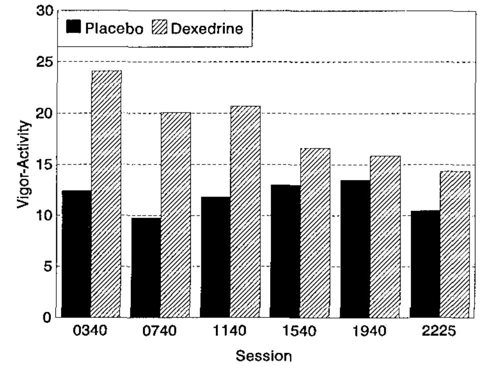

Figure 10. Effects of drug and time of day on POMS vigor-activity scores.

Fatigue-inertia. There was a drug-by-session interaction on fatigue-inertia ($F(5,50)=7.94$, $p<.0001$) which was due to higher scores under placebo than Dexedrine® during every session except for the one at 1940 ($p<.05$), as can be seen in figure 11. There also was a session main effect ($F(5,50)=7.41$, $p<.0001$). This was because of significantly lower scores at 0340 than 0740, 1140, 1540, 1940, or 2225, and lower scores at 1140 than at 0740 or 2225 ($p<.05$). There was a drug main effect ($F(1,10)=17.71$, $p=.0018$) which was because of higher overall scores under placebo than Dexedrine®.

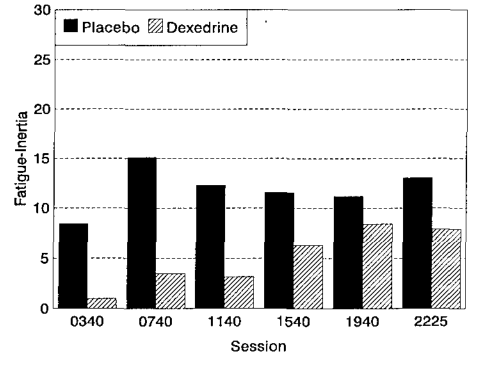

Figure 11. Effects of drug and time of day on POMS fatigue-inertia scores.

Confusion-bewilderment. There was a drug-by-session interaction on confusion-bewilderment ($F(5,50)=5.98$, $p=.0002$) which was due to the fact there were greater feelings of confusion under placebo versus Dexedrine® during the morning, but not later in the day. Analysis of simple effects revealed differences between the dose conditions (higher scores under placebo than Dexedrine®) at 0340, 0740, and 1140 ($p<.05$),

while a similar effect was not seen from 1540 until 2225 (see figure 12). There was an overall session main effect ($F(5,50)=3.57$, $p=.0078$) as well which contrasts indicated was due to increases in confusion-bewilderment scores from 0340 to 0740 and 1540, while there were decreases from 0740 to 1140 ($p<.05$). There also was a drug main effect on this scale ($F(1,10)=9.91$, $p=.0104$). This was due to higher overall scores under placebo than under Dexedrine®.

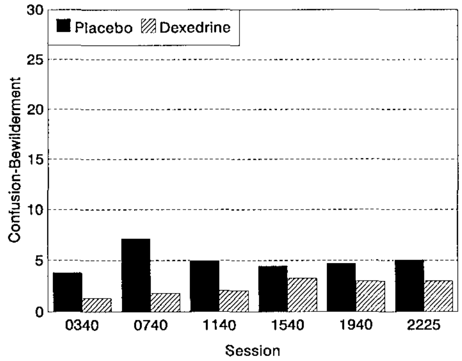

Figure 12. Effects of drug and time of day on POMS confusion-bewilderment scores.

DISCUSSION

Flight performance

The flight data revealed there were overall drug-related performance effects on every maneuver with the exception of the hovers. This supports earlier anecdotal reports that Dexedrine® is effective for maintaining aviator performance in the in-flight environment.[5,6] The low-level navigation, straight-and-levels, climbs, descents, left and right standard-rate turns, and the left descending turn all were improved by the administration of Dexedrine® in comparison to placebo. In addition, there were interactions between drug condition and time of day on the straight and levels, climbs, descents, and the left standard-rate turns. In each case, there was no difference between performance as a function of Dexedrine® versus placebo at the 0100 flight when subjects had not yet begun to experience the full effects of sleep deprivation (this was only 2 hours past their normal bedtimes). However, Dexedrine® consistently produced better performance than placebo at 0500 and 0900 when the combined fatigue from sleep loss and the circadian trough tended to be greatest. The 1300 and 1700 flights in these maneuvers were variably affected by the drug conditions. In the straight and levels and in the descents, Dexedrine® continued to markedly improve afternoon performance as it had done earlier in the day. However, during the climbs and the left standard-rate turns, there were no drug-related differences at 1300 and 1700.

A close examination of each of the drug by time-of-day effects suggests that Dexedrine® essentially maintained performance at pre-deprivation levels throughout the sleep-loss period. However, under placebo, marked decrements occurred particularly at 0500 and 0900, followed by a tendency toward a circadian-influenced recovery at 1300 and 1700. This slight recovery under placebo during the afternoon flights accounts for the lack of significant differences between Dexedrine® and placebo at 1300 and 1700 during the climbs and the left standard-rate turns. However, it should be reiterated that *overall* performance under Dexedrine® was better than overall performance under placebo during virtually every segment of the flight profile.

Another noteworthy drug-related finding was that the differences between Dexedrine® and placebo tended to be accentuated when the difficulty of the maneuvers was increased. For instance, during the straight-and-levels, the largest differences between Dexedrine® and placebo were observed during the fourth iteration of this maneuver, when the automatic flight stabilization system (the AFCS) was disengaged. A similar effect was observed during the left standard-rate turns where there was no noticeable difference between Dexedrine® and placebo during the first iteration (with AFCS), while Dexedrine® produced better performance during the second iteration (without AFCS). In addition, although all of the descents were flown with the AFCS turned off, the performance improvements under Dexedrine® were most obvious during the third iteration of the descent, which was twice as long as the first and second iterations. Thus, it is important not only to consider the general effects of sleep deprivation on the abilities of aviators to fly routine missions, but to consider how these effects of sleep loss will be accentuated as workload demands increase.

There were no overall differences in performance between males and females. There were gender-related interactions on four of the maneuvers, but only one of these indicated a different sensitivity to drug and/or sleep loss as a function of gender. Analysis of the descents showed performance declined from the first to the third descent in the males under placebo (but not Dexedrine®), whereas this did not occur in the females. However, this effect appears to be of no practical significance, and in light of the virtual absence of other important gender differences, it seems reasonable to discount gender as a factor in this context.

Electroencephalographic data

The EEG data analyzed from the midline electrodes indicated that there were drug effects consistent with what was found in the flight performance results. Under the influence of placebo, there were overall increases in the type of slow-wave (delta and theta) activity that is normally associated with decreased alertness and/or sleep deprivation.[11,12] Dexedrine® mitigated

this effect as it did the decrements in performance which were seen in the flight simulator.

There also were several drug-by-eyes interactions within the delta, theta, and alpha bands. The findings with regard to delta and theta were generally supportive of the main effects discussed above (decreased slow-wave under Dexedrine® versus placebo); however, it was evident that these effects were clearer under the eyes-closed condition than the eyes-opened condition. In fact, drug-related changes in delta at Fz, Cz, and Pz were observed only during eyes closed. Similar changes occurred in theta at Cz and Pz, where although the differences were significant both during eyes-open and eyes-closed, they were most pronounced under the eyes-closed condition. The drug-by-eyes interactions in alpha activity at Fz and Cz, were similarly due to more pronounced differences during eyes-closed rather than eyes-opened. In the case of alpha activity, there was more alpha under Dexedrine® than placebo at both recording sites--indicating subjects were better able to maintain wakefulness under Dexedrine®. These findings show that it is easier to detect shifts in alertness while subjects are sitting quietly with their eyes closed than with their eyes open. This is because the increased temptation to sleep (which would bring about more slow-wave EEG and less alpha EEG) is greater when subjects are offered the opportunity to close their eyes.

There were few instances of gender-related effects on EEG activity. In fact, while there were three, three-way interactions, the most consistent gender-related finding was a drug-by-gender interaction involving the amount of delta, theta, and beta activity at Oz. This was because greater delta, theta, and beta activity was present under placebo than under Dexedrine® at Oz in the females, while there were no differences at this electrode location in the males. However, this effect does not appear to be of any practical significance in terms of the overall benefits of Dexedrine® in a sustained-operations context-- especially in light of the fact that there were several other overall Dexedrine®-related effects which demonstrated the positive effects of this drug in both males and females.

Profile of mood states

The subjective feelings of anger, vigor, fatigue, and confusion were in agreement with objectively measured performance/alertness. The first POMS of the day was administered at 0340 (1 hour and 20 minutes prior to the 0500 flight), and the scores indicated greater feelings of vigor-activity under Dexedrine® than placebo at this time of day. Conversely, there were greater feelings of fatigue-inertia and confusion-bewilderment under placebo than Dexedrine® at the 0340 test administration. On all 3 scales, the observed drug effects were evident at 0740 and 1140 as well, showing that subjects were feeling the effects of sleep deprivation under placebo and deriving the most benefit from Dexedrine® especially during the morning hours. Later in the day, at 1540 and 2225, subjects continued to feel more vigorous and less fatigued under Dexedrine® than placebo, although differences in confusion scores between the two dose conditions disappeared. In addition, regardless of testing session, there were overall drug effects on the anger-hostility scale which indicated greater anger under placebo than under Dexedrine®. These results, especially with regard to vigor and fatigue, are in agreement with Newhouse et al.,[13] who found that dextroamphetamine improved these ratings following a period of sleep deprivation.

Note that the most uniform Dexedrine®-related improvements found earlier in flight performance occurred at the 0500 and 0900 flights, and these were bracketed by the 0340 to 1140 POMS. However, there also were overall improvements in both flight performance and CNS indicators of alertness throughout the test days, and this finding is consistent with the overall improvements in vigor and fatigue which occurred regardless of the test times. The fact that there was greater vigor and less fatigue under Dexedrine® than placebo as late as 2225 shows that Dexedrine® continued to exert its effects long after the last dose was administered.

As was the case on both the flight and EEG data, gender typically did not affect mood ratings. In fact, there were only two gender-related effects, and only one of these indicated a relationship between the drug condition and sex of subject. On the anger-hostility scale, there was a tendency toward greater scores under placebo than Dexedrine® primarily in the males while the difference did not approach significance in the females. However, the practical importance of such an effect seems small especially in view of the fact that there were no differences between males and females on the vigor, fatigue, or confusion scales.

CONCLUSIONS

The results from twelve helicopter pilots during the final 23 hours of two 40-hour sustained operations periods showed that Dexedrine® was effective in maintaining flight performance, alertness, and mood. Pilot gender exerted no significant impact on performance as a function of sleep loss or the effects of Dexedrine®.

Of the nine sets of flight maneuvers, only the hovers were unaffected by whether subjects received Dexedrine® or placebo. Performance on the remaining maneuvers was maintained at pre-sleep-deprivation levels by Dexedrine®, whereas performance was compromised by fatigue and sleep loss under placebo. Although Dexedrine® effectively maintained performance throughout each test day, these effects were especially noticeable at the 0500 and 0900 flights where the combination of circadian effects and sleep deprivation was greatest. In addition, there were some interactions between workload and drug effects which indicated that Dexedrine® was particularly beneficial during the performance of more difficult flight tasks.

EEG indicators of alertness and subjective ratings of vigor, fatigue, and confusion were consistent with the flight results. Generally, there was less slow-wave EEG activity (an indicator of fatigue) after Dexedrine®, and subjects reported feeling more active, less tired, and less confused under the influence of Dexedrine®. The subjective reports coincided well with the performance data in that the most pronounced effects of Dexedrine® were observed in the morning hours (around the times of the 0500 and 0900 flights).

In summary, it can be concluded that properly administered 10-mg doses of Dexedrine® will effectively *prevent* most of the performance losses attributable to moderate sleep deprivation, without creating unwanted side effects. It remains to be determined how effective Dexedrine® will be for sustaining performance beyond a 40-hour period.

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The views, opinions and/or findings contained in this abstract are those of the author and should not be construed as an official Department of the Army position, policy or decision unless so designated by documentation.

In the conduct of research where humans are the subjects, the investigator adhered to the policies regarding the protection of human subjects as prescribed by 45 CFR 46 and 32 CFR 219 (Protection of Human Subjects).

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THE EFFECT OF MODAFINIL AND AMPHETAMINE ON CORE TEMPERATURE AND COGNITIVE PERFORMANCE USING COMPLEX DEMODULATION DURING 64 HOURS OF SUSTAINED WORK

by

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1. INTRODUCTION

Modafinil (diphenylmethyl-sulfinyl-2 acetamide) is an alerting substance that is considered safer than amphetamine with fewer side effects [17]. It appears to produce no feelings of euphoria, does not seem to be addicting, induces no drug tolerance and in large dosages (>4500 mg) does not produce serious medical problems [19]. These features make modafinil a good candidate to reduce or ameliorate the effects of prolonged sleep loss in military operations [13]. The validity of these claims, however, is in question due to the very few number of controlled studies using normal adult subjects [19]. Modafinil has been used primarily in either clinical studies to treat sleeping disorders (e.g., [3, 5, 6, 16, 17]) or in animal studies to investigate its pharmacological properties (e.g., [8, 11, 18, 21]). Modafinil is described as an alpha-1 adrenergic agonist [25, 19], but Mignot *et al.* [20] have recently questioned this interpretation, reporting that modafinil had good selectivity for the dopaminergic transporter. Nevertheless, the relatively benign psycho-pharmacological properties of modafinil make it a good candidate to reduce or ameliorate the cognitive effects of prolonged sleep loss under continuous workload conditions. Presently, use of modafinil in Canada is limited to scientific and/or clinical investigations.

Of the studies performed on healthy human adults, none has demonstrated the relative effectiveness of modafinil under sleep loss conditions involving more than 1 night or under continuous workload conditions [4, 27]. Although sleep loss studies have repeatedly demonstrated that sleep deprivation is associated with higher levels of (subjective) fatigue and sleepiness as well as poorer cognitive performance [10, 14, 22, 23], such studies are often characterized by a paucity of behavioural tasks administered relatively infrequently. Also, the tasks are typically not cognitively demanding and may be separated by long periods of leisure activity (e.g., reading or watching movies). For these reasons Angus and Heslegrave [1] suggested that performance declines due to sleep loss reported in many studies may be conservative and not reflect performance impairment expected in actual work environments. Their work showed that when sleep deprivation is coupled with intensive cognitive work, performance decrements of 30-40% are found during the first night and 60-70% decrements are observed during the second night without sleep [1, 2]. The efficacy of modafinil to counteract these severe performance declines is largely unknown. The results of Bensimon et al. [4], where healthy subjects showed positive effects of modafinil after a single night of sleep loss with low workload, are suggestive but cannot be extended to include more extreme, and operationally more relevant, conditions.

In the present paper, we will summarize an international collaborative experiment performed at DCIEM to investigate the maintenance and recuperative effects of modafinil against d-

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amphetamine and placebo during 64 hours of sleep loss requiring continuous cognitive work. We will then re-analyse a portion of these data using a procedure called Complex Demodulation that effectively acts as a digital band-pass filter, allowing much better discrimination of the circadian effects of sleep loss and its interaction with the drug conditions.

2. 64 HR SLEEP LOSS STUDY

The study summarized here is covered in more detail in Pigeau et al., [24] and Buguet et al. [7]. Only the key findings will be discussed here, and only three results from the Pigeau et al. paper will be expanded upon using complex demodulation (i.e., core temperature, logical reasoning task and serial reaction time task.

2.1 Method

Forty-one Canadian Forces reservists participated in this study, each receiving their regular duty wages plus a stress allowance. All subjects were pre-screened by a physician using a medical questionnaire and classified as fit to participate in the experiment . Upon arrival at the laboratory, the subjects were briefed on the experiment and provided written informed consent to participate in the study.

Seven groups of 6 subjects (except for one of the placebo groups, which had only 5 subjects) were run concurrently for 6 continuous days in a self contained windowless laboratory. Although the subjects were informed that they would receive a drug treatment three times during the experiment, they were informed neither when the treatments would be given nor which drug they would receive. The subjects received either 300 mg of modafinil, 20 mg of d-amphetamine, or placebo on 3 separate occasions during 64 hours of continuous cognitive work and sleep loss. A drug treatment was administered after 17.5 hours of wakefulness at 23:30 h of the first night without sleep (at the circadian acrophase) to determine if modafinil and amphetamine versus placebo would counteract the expected decline in cognitive performance. In order to investigate the recuperative effects of modafinil and

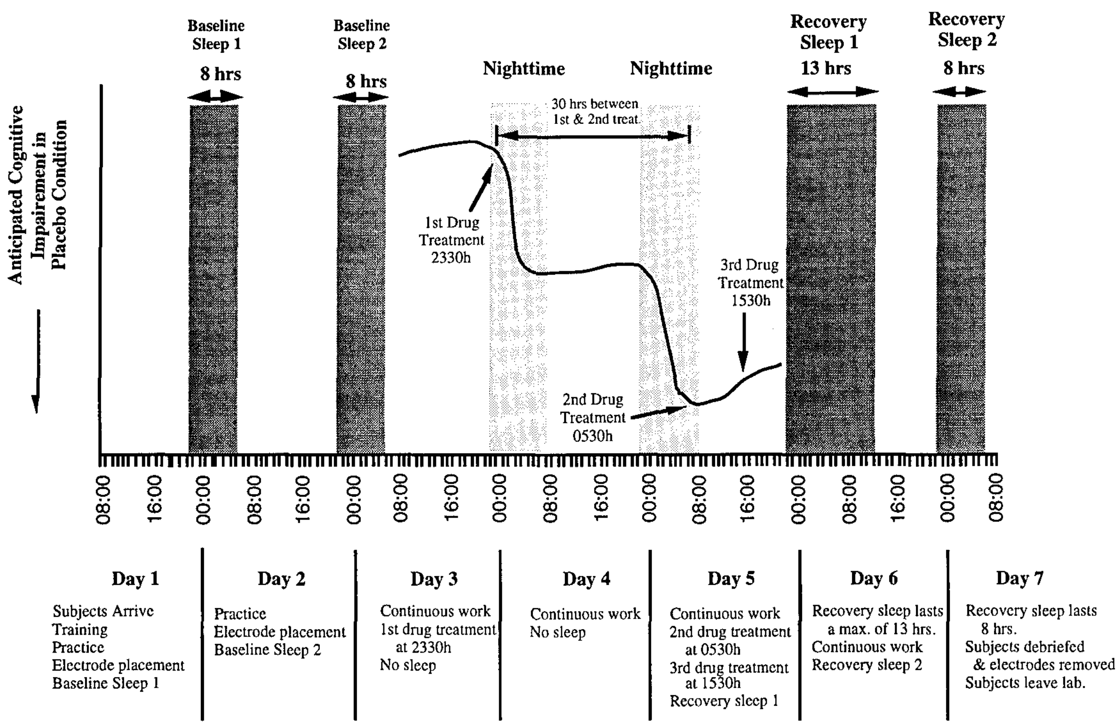

Figure 1: **Experiment Protocol** — 12 subjects in each of the 3 drug conditions (Modafinil, amphetamine & placebo) will receive the same protocol.

amphetamine, a second drug treatment was given 30 hours later at the circadian nadir of the second night without sleep (i.e., at 05:30 h after 47.5 hour of wakefulness) when cognitive performance for all three drug conditions should be at its lowest. Finally, a third drug treatment was given at 15:30 h (10 hours later) to investigate the effect of modafinil and amphetamine on recovery sleep — see Figure 1 for a graphical depiction of the study.

The subjects worked continuously in 1.75 hr work sessions, with 15 min. breaks devoted to experimental and subject related needs (e.g., checking the electrodes, eating, using the lavatory, etc.). During these breaks, core temperature was recorded. Throughout the entire experiment, administration of drugs followed double blind procedures.

Although subjects worked on a battery of 30 cognitive tasks and questionnaires, only results from the following will be presented: 1) serial reaction time task given every hour, 2) logical reasoning task given every hour, and 3) core body temperature sampled every two hours.

2.2 Results and Discussion

Fig. 2 illustrates core body temperature as measured by surface mounted Deep Body Temperature sensors. [Note: The core temperature results contains the data from only 5 amphetamine, 5 placebo and 11 modafinil subjects because the equipment was unavailable for the earlier runs.] A clear circadian rhythm is present for the placebo group. A 3 between (drug condition) by 2 within (treatments 1 and 2) by 5 within (10 hours) ANOVA yielded a significant three-way interaction. Compared to the placebo group, the circadian rhythm for the amphetamine and modafinil groups are suppressed after administration of the first drug treatment and elevated during the second drug treatment. It appears that amphetamine and modafinil raise body temperature and thus disrupt the natural circadian rhythm.

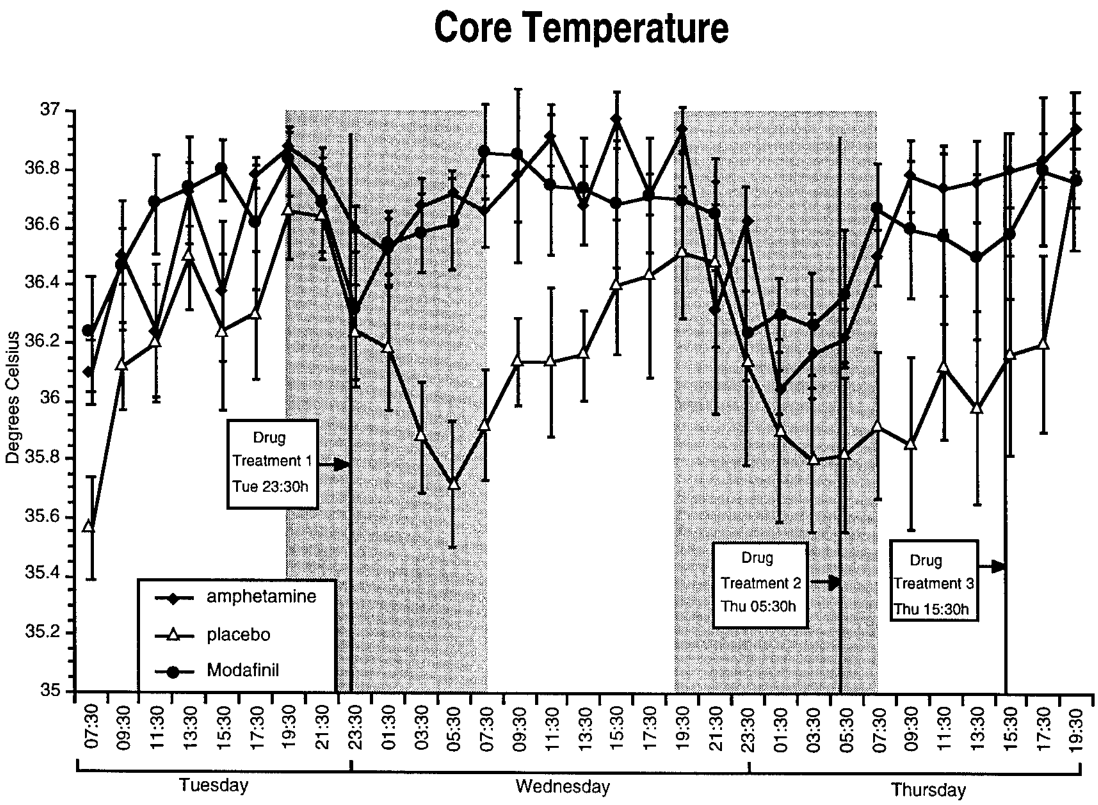

Figure 2: Mean (± SEM) of core temperature

Logical Reasoning Task

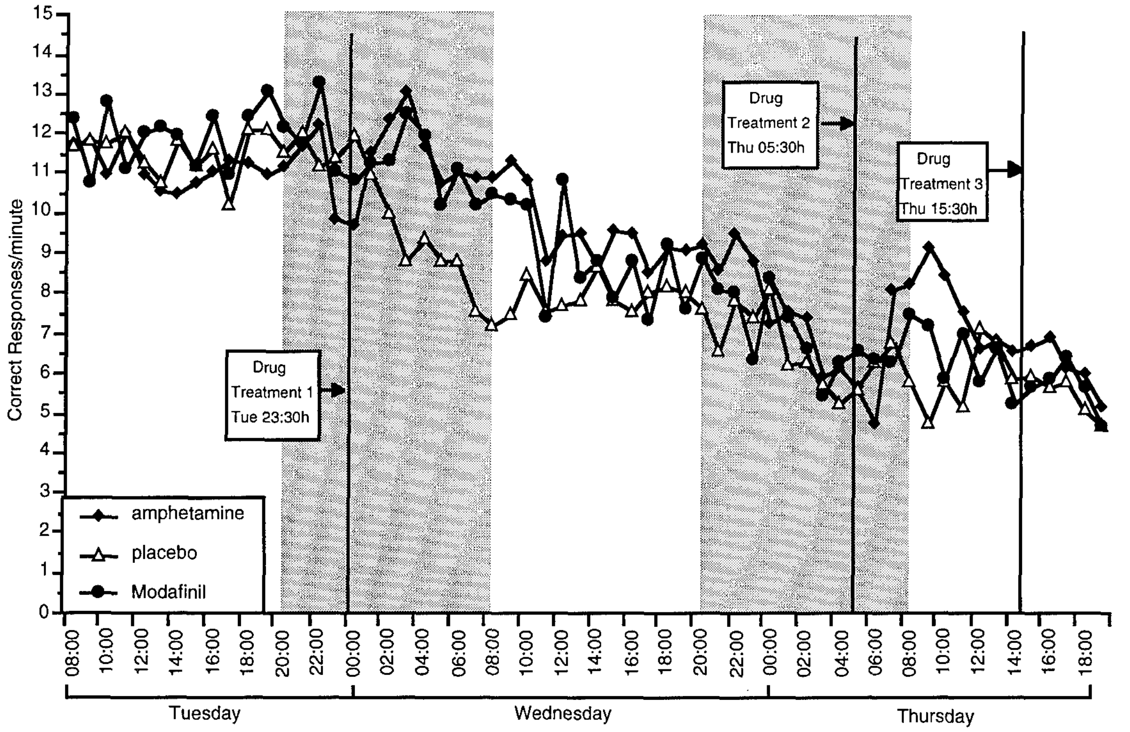

Figure 3: Mean number of correct responses per minute for the logical reasoning task.

Serial Reaction Time Task

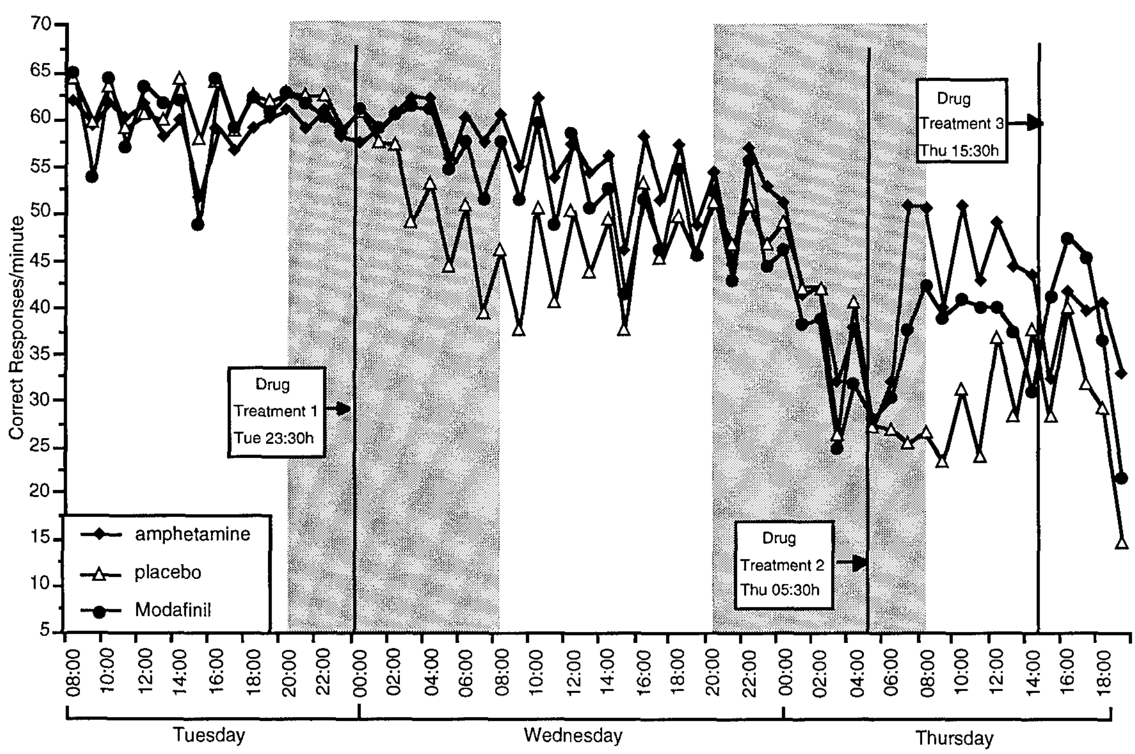

Figure 4: Mean number of correct responses per minute for serial reaction time task

For both the logical reasoning and the serial reaction time tasks (see Figures 3 and 4) during the 10 hours following the first drug treatment, the placebo group demonstrated the anticipated circadian decline in mood and performance whereas both the modafinil and amphetamine groups did not. For the 10 hour period following the second drug treatment, mood and performance improved for the amphetamine and modafinil groups compared to the placebo group; no differences were observed between modafinil and amphetamine.

The results for the placebo group in the experiment replicated findings from previous (non drug) sleep loss studies involving continuous work [1, 12]. Although modulated by the circadian cycle, performance on the two cognitive tasks varied consistently as a function of sleep loss. Taken as a percentage of the level of baseline performance (i.e., from the beginning of the experiment), the placebo group demonstrated a 30-40% decrement in performance after the first 24 hours and a 55-65% percent decrease after 48 hours without sleep. In contrast, both the amphetamine and modafinil groups experienced only a 5-10% decline in cognitive performance after the first 24 hours of sleep loss (10 hours after drug ingestion). Although both groups showed performance declines comparable to the placebo group after 48 hours (i.e., 55-65%), the second drug treatment improved performance to a level 20-30% below baseline for both the amphetamine and the modafinil groups. There were no differences between modafinil and amphetamine in their ability to either ameliorate or recuperate mood and performance during the 10 hours post drug administration for either the first or second drug treatment.

On the morning of the last day of the experiment, a detailed debrief was carried out with all subjects. In a group, each subject responded to the following questions: 1) for each time you were given a drug, which drug do you believe you received? and 2) for each time you were given a drug, did you notice any effects? (if yes, what were they?). During the debrief, 53% of the subjects who actually received amphetamine responded that they thought they had been given amphetamine. Similarly, a large portion (49%) of the placebo group felt that they had not received any drug. Subjects in the modafinil group, however, were much more equivocal about their estimates: 26% amphetamine, 39% modafinil, 27% placebo and 7% did not know. These results are consistent with anecdotal comments made by the subjects during the study. Those given amphetamine often reported positive affect 2 hours after drug administration— e.g., 'feeling great', 'what a kick'; placebo subjects on the other hand were often sullen; while modafinil subjects were neutral in their comments — 'fine', 'feel ok', 'no problem'. The affective difference that best described the two drug conditions was that amphetamine subjects experienced heightened arousal whereas the modafinil subjects simply felt less fatigued. However, given the subjective nature of these data, the putative safety of modafinil should be interpreted cautiously.

Recall that the third drug treatment was included to assess the effect that each drug condition would have on recovery sleep. As expected, the placebo group demonstrated slow wave sleep (SWS) and REM rebounds during the first night of recovery. SWS rebound occurred mainly during the first half of the night, while the REM rebound was distributed evenly across REM sleep episodes. Recovery sleep for the amphetamine group increased sleep latency and intrasleep wakefulness, decreased total sleep time and sleep efficiency and decreased REM sleep with a longer REM sleep latency. In fact, REM sleep rebound continued into the second night of recovery sleep. The modafinil group on the other hand, exhibited decreased time in bed and asleep suggesting a lesser requirement for recovery sleep than the other two groups. REM sleep rebound was limited to the first REM sleep episode and there were fewer disturbances than the amphetamine group during the first recovery night.

2.3 Conclusions

In conclusion, modafinil appears to be as effective as amphetamine in maintaining cognitive performance during the first night without sleep, and partially recovering performance after 48 hours of continuous work. Modafinil did not interfere with recovery sleep, it elicited sleeping patterns similar to those of the placebo group and it decreased the need for a long recovery sleep. Although research must be performed to study the long term effects of modafinil on normal subjects, long term clinical studies on narcoleptics suggests that modafinil does not induce tolerance or drug

dependence, nor does it have severe side effects [3, 6]. On the whole, modafinil may be an attractive alternative to amphetamine for maintaining or recovering performance during periods of continuous work and sleep loss.

3. Complex Demodulation

Since many of the tasks reported in Pigeau et al.[24] were performed every hour throughout the sleep loss portion of the experiment, a 'break' effect, was evident in the results due to the arousal inducing value of the 15 minute break given to the subjects every 2 hours. Preliminary analyses showed that the break improved performance when compared with the same task presented 1 hour later in the session. This can be seen in Figure 4 where the placebo group exhibited a 'saw-tooth' shape pattern. For ease of interpretation, Pigeau et al. plotted these results separately for those trials occurring after the break and those trials occurring 1 hour into the session. Essentially the 'break' effect masked (or at least made it more difficult to see) both the circadian effect and the decreasing trend in performance due to fatigue. Compare Figures 3 and 4 in this paper with Figures 8 and 9 in Pigeau et al. [24]. This problem is representative of a general class of problem: how to extract periodic trends that are embedded in a time series that includes noise and other trends.

Often frequency domain techniques such as Fourier analysis and autocorrelation have been used to extract temporal regularities in time-series data. But if the time series changes in phase or amplitude during the period under observation these techniques may be inappropriate. Complex demodulation is a time domain method of analyzing time-series data that does not assume stationarity. It is sensitive to moment-to-moment changes in phase and amplitude and yields a time-series as output. As such, complex demodulation acts as a digital band-pass filter for any single frequency under consideration. For a complete description of complex demodulation see [9, 26, 28-32].

3.1 Method

A Microsoft® Windows™ based program called WinCD (version 1.0) written by Tim Elsmore[1] was used to perform complex demodulations on the time-series data from the core temperature and the cognitive tasks. Complex demodulation was performed twice on the raw time series of each subject: the first filtered for circadian influences (i.e., 1 cycle/24 hrs) and the second filtered for the 'break effect' (i.e., 12 cycles/24 hrs). For both, the linear component of the time series was left intact to reflect the general decline in performance resulting from sleep loss. The filtered time series for each subject were averaged (point by point), yielding mean curves (with standard errors) for each task and drug condition.

3.2 Results and Discussion

Figures 5, 6 and 7 show the circadian rhythm (and linear trend) for the core temperature, logical reasoning and serial reaction time data respectively. Compared to Figures 2, 3 and 4 the effects due to drug condition are much more apparent. Three between (drug condition) by 2 within (treatments 1 and 2) by 10 within (10 hours or sessions) ANOVAs on the complex demodulated data for the logical reasoning and serial reaction time tasks show the same pattern of effects as those found using the raw data — compare Table 1 with those reported in Table 1 of Pigeau et al.[24].

Logical Reasoning task		
Drug (Amp, Modafinil, Plac)	F=2.7	p<.0826
Treat (treatments 1 and 2)	F=88.3	p<.0001
Session (1-10)	F=24.0	p<.0001
Drug x Treat	F=.12	p<.8841
Drug x Session	F=2.63	p<.0004
Session x Treat	F=6.49	p<.0001
Drug x Treat x Session	F=3.47	p<.0001
Serial Reaction Time task		
Drug (Amp, Modafinil, Plac)	F=5.4	p<.009
Treat (treatments 1 and 2)	F=123.8	p<.0001
Session (1-10)	F=6.56	p<.0001
Drug x Treat	F=.146	p<.64
Drug x Session	F=5.5	p<.0001
Session x Treat	F=51.4	p<.0001
Drug x Treat x Session	F=7.6	p<.0001

Table 1: ANOVA table for CD data.

Core Temperature
(Complex Demodulation)

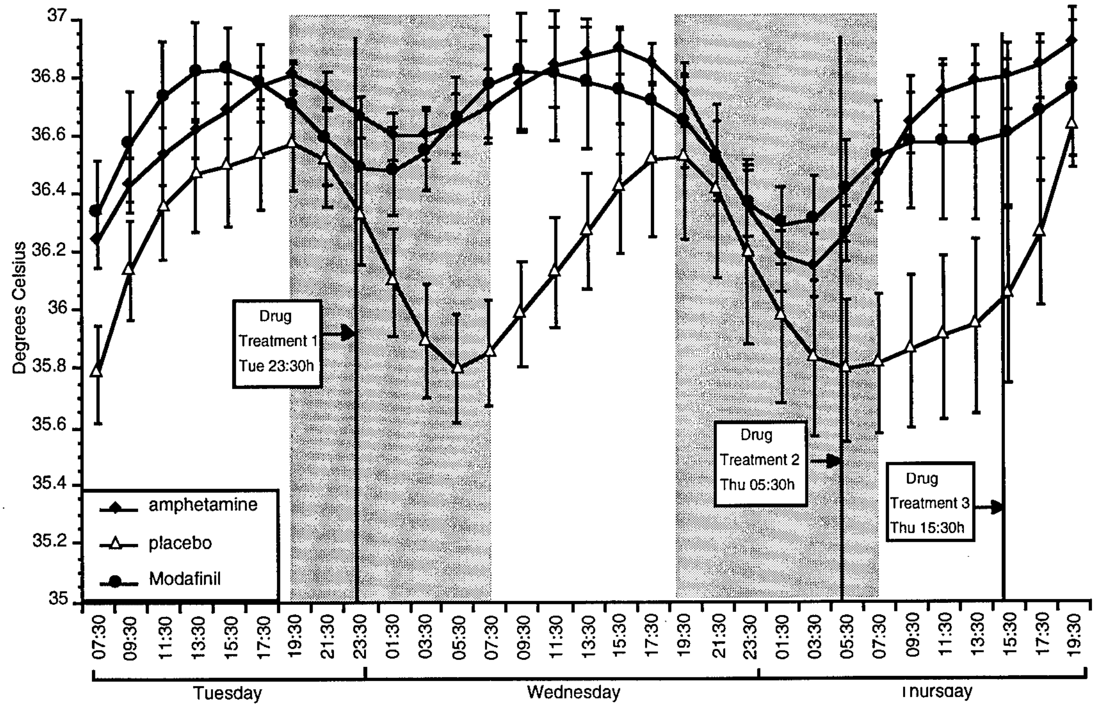

Figure 5: Means (± SEM) demodulated core temperature

Logical Reasoning Task
(Complex Demodulation)

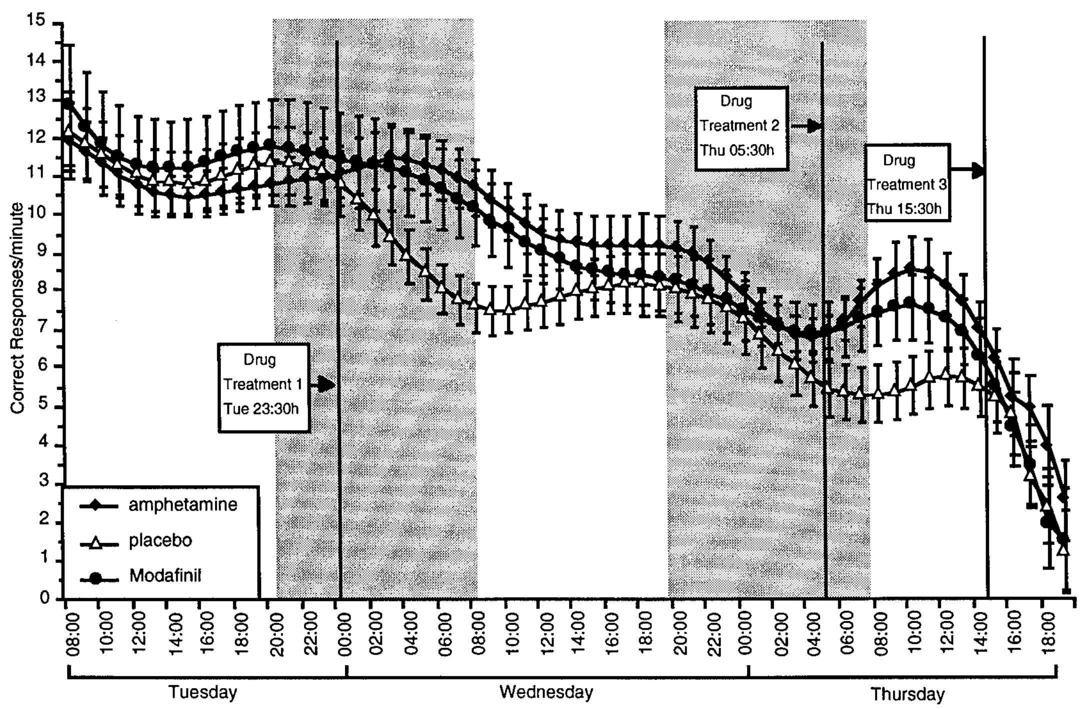

Figure 6: Means (± SEM) of demodulated correct responses per minute for logical reasoning task

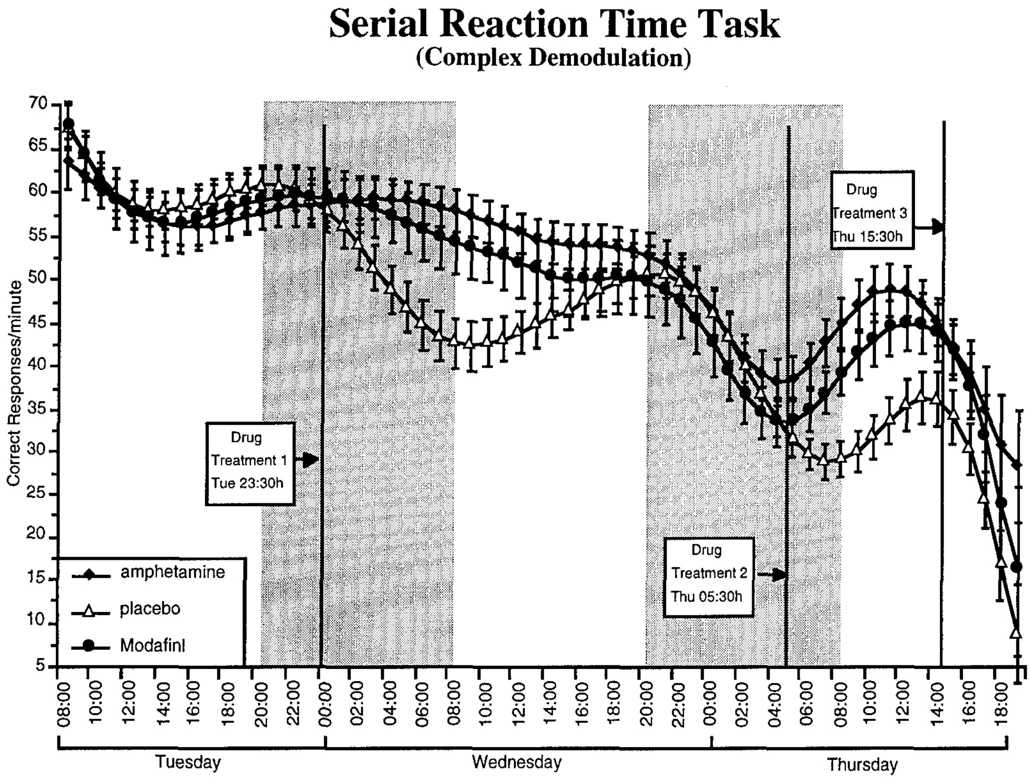

Figure 7: Means (± SEM) of demodulated correct responses per minute for serial reaction time task

This suggests that although the complex demodulation procedure yielded clearer effects, it did not significantly change the pattern of results found in the original time series. This conclusion is supported by Table 2 where the mean percentages of variance explained by complex demodulation are listed. For the circadian effect (which includes the decreasing linear trend) complex demodulation accounted for 70-80% of the variance contained in the original core temperature data. Similarly, 54-68% of the variance in the logical reasoning task and 55-73% for the serial reaction time task were accounted for. The break effect (12 cycles/day) which oscillated every two hours during the sleep loss period accounted for a large portion of the remaining variance in the original time series: 61-74% for logical reasoning and 62-78% for serial reaction time. Also from Table 2, the Placebo group consistently accounted for more of the variance than did either the amphetamine or the modafinil groups (the differences being statistically different for only the serial reaction time task: $F_{(2,38)}=3.94$, $p<.028$ for circadian effect and $F_{(2,38)}=4.4$, $p<.019$ for the break effect). This is not surprising since the placebo group, not having received the beneficial effects of alerting substances, produced much larger circadian and break effects.

Core Temperature

	Circadian
Amphetamine	69.8 (±5.78)
Placebo	80.3 (±3.95)
Modafinil	74.5 (±3.73)

Logical Reasoning Task

	Circadian	**Break**
Amphetamine	61.1 (±6.42)	65.9 (±5.86)
Placebo	68.0 (±4.50)	73.8 (±3.46)
Modafinil	53.6 (±7.97)	60.7 (±6.87)

Serial Reaction Task

	Circadian	**Break**
Amphetamine	55.4 (±3.99)	62.2 (±3.49)
Placebo	72.9 (±2.14)	78.2 (±1.49)
Modafinil	63.1 (±4.78)	71.0 (±3.28)

Table 2: Mean percentage variance explained (with SEMs) by complex demodulation for each of the circadian (1 cycle/day) and the break effect (12 cycles/day). **Note:** Break effect variances calculated on residuals of the circadian effect.

3.3 Conclusion

If data are sampled equally over time, complex demodulation is a good technique for filtering time series and isolating rhythmical effects. It adapts itself to changes in amplitude and phase and yields a new transformed time series. Complex demodulation allowed a much better depiction of the effects of amphetamine and modafinil as alerting substances during 64 hours of continuous work. It clearly showed the suppression of the circadian rhythm in core temperature for amphetamine and modafinil, and also clearly displayed the maintenance and recuperative effects of these drugs versus placebo. It is suggested that complex demodulation should be used more often in research where the influence of rhythmical effects in time series need to be estimated.

4. Footnotes

[1] WinCD is available for a nominal handling fee of $10 (US) from its author Dr. Tim Elsmore, Activity Research Services, 10284 Perez Court, San Diego, CA 92124.

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HEAVY JET OPERATIONS: PRESENT CONCERNS IN CURRENT DEVELOPMENTS

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Summary.

This title opens up many aspects of modern commercial aviation for discussion. Having just been through a two and a half year project introducing Airbus modern technology aircraft to Cathay Pacific Airways we have had some insight to the challenges and problems ahead in this very complex industry. Since November 1994, over a period of 13 months we have entered into service 11 aircraft, 4 Airbus A340 and 7 Airbus A330 wide-bodied advanced technology machines. In that time we have trained 220 pilots, matured our in house training program, gained CAT 3 landing approval, and started the process of Cross Crew Qualification (CCQ) between the two types with Mixed Fleet Flying (MFF) to follow. Less than one third of these pilots where trained with any assistance from the manufacturer. By the end of 1996 we should be a mixed fleet size of 17 aircraft with another 16 options on the books. I would like to focus on the many challenges, concerns and lessons learnt during this phase. In doing so I will cover Technology, Training, Human Factors (Culture), Support Systems, External Factors.

1. New Technology

There will always be new technology. Efficiency is the designers goal, and big advances in efficiency can come with new technology. There are huge economic benefits for Airlines operating the "Fly By Wire" and "Modern Wing" technology both from the point of view of fuel efficiency and improved maintenance efficiency. Are Airlines ready for the hidden changes in their structure to support this technology? Do Airlines have new Training systems in place to support the demand that pilots understand the subtle changes, of computer driven aircraft? Have the Airlines carried out the research to fully prepare themselves for the change in thinking required?

A look at the advances in aviation technology since the Wright brothers first flew, reveals some landmark jumps in technology. At the beginning, biplanes gave way to monoplanes. Then propulsion systems moved from piston to jet, leading to quantum increases in speed. Straight wings became swept to accommodate high subsonic speed, and then supersonic aircraft arrived. Small narrow-body transport aircraft swelled to giant wide-body aircraft, and eventually new flight instrument presentations arrived. Now, computer power is harnessed to provide more user-friendly displays, and electronic flight control. All of this has lead to a reduction in flight crew from five-man crews to the two-pilot crews of today directing the "expert systems" of the modern airliner.

At each of the landmark jumps in technology came new handling qualities, requiring new piloting skills. Usually, traditional techniques and procedures from the previous generation of aircraft were only of partial value, and pilots had to learn new tricks.

On the other hand some impressive engineering solutions based on efficiency, weight and engineering simplicity have resulted in only scant consideration of the "man-machine" interface. It has always been expected that Pilots will adapt. More recently, considerable efforts have been made to design aircraft for the operators, but pilots still find unfriendly "engineering solutions" on the modern flight deck which could have been tailored more appropriately to operational needs. It is refreshing to see that Airbus have taken a recent initiative to invite a particular group of pilots from user Airlines to most expertly identify the best ergonomic "man-machine" solutions of the future generation aircraft. It is interesting to note they have made a specific request to exclude the most senior management pilots. What is often not recognized is that pilots are usually conservative by nature. Perhaps this is a genuine attempt to drive the best of Flight Deck design from the point of view of plucking and developing the strong features which one can find from every manufacturer.

Parallel to the dramatic leaps of technology, people have remained relatively unchanged. Human evolution is measured at a snail's pace compared with the technology of modern times. However, if the private car of today were designed to handle like a "Model T Ford" or "Morris Oxford", the public would nevertheless consider such a concept as inappropriate and ridiculous, demonstrating that perceptions have indeed changed with technical progress.

Immediately following almost all historical leaps in aviation technology, there were traumatic periods of adjustment in the industry. During the "changeover periods", accident rates rose, and the cynics prevailed for a while. Surprisingly, with almost every change, pilots were often exposed to traditional training programs which were ill-suited to the new technology. Designers also fell into the trap that automation would protect human frailties. Military accident rates rose dramatically during peace-time periods of adjustment, particularly post war with the introduction of jets, and later with the introduction of early military "fly-by-

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wire", "Head Up Display" fighters. Too little emphasis was placed on operational differences, or on research of how the "man-machine" interface had changed. Appropriate pilot training for new technology was always established eventually, but often only some time after the new aircraft had entered service.

Research.

Accepting in Cathay Pacific that a prerequisite to any successful introduction for what for us was a reasonable step forward in technology and a new marriage with a completely unfamiliar manufacturer, much research had to be done. We used the medium of talking extensively to other airlines and had two pilots fly the technology using our sister company's A320 operation into China. From this we reached the following conclusions:

- These aircraft are highly computerized and not just an expansion of traditional systems with the addition of glass. In many ways the intermeshing of computer systems throughout the aircraft and the new visual cue's is a major issue in itself which has to be understood.
- That the **Interface of Man and Machine** is an important training issue in the successful understanding and operation of this technology.
- Lessons from the past indicate that with any large change there has always been an element of human reversion to old habits under pressure. **Training courses must include full consideration of the need for trainee pilots to dump old concepts and learn to adapt to new ones.** To balance this there are some old habits which should not be dumped. These must be identified.
- We felt that in the main, the solutions lay in the correct TRAINING from the outset.
- There should be an element of Preconditioning before training started. Solved by early Newsletters and pre-course reading to lay some foundation as to the what the technology is all about.
- A series of in house seminars was needed to discuss the basics of "Fly By Wire" and the fully automated flight decks with a major focus on any accidents or incidents to date.
- Training time was definitely reduced by the level of enthusiasm for new technology. This was the basis for our decision to allow the launch team of both Check and Training as well as line pilots to be from a pool of volunteers taken in seniority.
- We needed much thought into having the right Training Tools.
- Glass screens for Primary Instruments is an issue for those pilots from analogue cockpits. A pilot quote to me once: *"My first glass experience was like standing with my mouth open trying to drink from a fire hose".*

2. Training

The Training Climate.

Prior to the present aviation recession, resources were in reasonable supply to provide for research into improved flight crew training. Since the deepest point of the recession, the huge airline deficits of the world have resulted in an environment of "slash and burn", with resources re-allocated to survival. Advanced CRM (Crew Resource Management) and LOFT (Line Oriented Flying Training) training concepts, just launched in many airlines, became still-born or were canceled. It has been a testing time for Airline Management to show real commitment to improved training schemes, which usually cost some resources to launch. However, when faced with the introduction of new technology aircraft, no airline should compromise in the area of training and CRM; both essential requirements for the safe introduction of new technology aircraft.

Operational Training.

Traditional pilot training methods assumed the need for pilots to learn through various "phases" of training, from ground school (technical) through simulator, to flight training. However, this process misses a fundamental point. Pilots will not be operating the aircraft in a "phased" manner, moving slowly from theory to practice. They will be using all skills simultaneously. Their perspective at work on the flight deck is "operational". They need to know at the start of their training "how" to operate the aircraft as a practical integrated activity. The traditional separation of the necessary skills in training carries the subconscious lesson of compartmentalization into the flight deck, when their job is really multi-faceted. The different instructors involved in each phase inevitably bring differing emphasis to the trainee, and sometimes inappropriate information, requiring "unlearning" and re-learning later in their operational environment. Confusion sown during early training can become an accident factor later.

In order to overcome the limitations of conventional flight training, when applied to new technology aircraft, Lufthansa and Cathay have independently developed transition courses designed by flight crew aimed at more operational and seamless learning. Each day, a combination of training aids is blended together to produce an immediate transfer from theory to practice. Computer Based Training, using checklists and procedures in use, combined with same-day simulator sessions, completes the circle of operational integration. Frequent emphasis on CRM (Crew Resource Management) and LOFT (Line Oriented Flying Training) is now becoming an integral part of the "Cathay Training Culture", important at any level of flight training.

Automation.

"Comments from a number of publications show that cockpit automation increases, decreases, and redistributes workload. It enhances situational

awareness, takes pilots out of the loop, increases head-down time, frees the pilot to scan more often; reduces or increases training requirements; makes a pilot's job easier, increases fatigue, changes or fails to change the role of the pilot, makes things less or more expensive; is highly reliable or highly unreliable, minimises human errror, leads to error, changes the nature of human error, tunes out small errors, raises likelihood of gross error; is desired by pilots, is not trusted, leads to boredom, frees pilot from mundane, and finally increases or has an adverse affect on safety."
(Adapted from comments by J. Lauber)

There is much said in the industry about automation. As one can see from extracts taken above, there is widly differing views. For new transport aircraft, improvements in efficiency demand that pilots understand the changes, and find new ways to operate. There is concern in the industry at the trend of airlines to have unclear "policies" on the use of automation by pilots. We have just developed our own which should help the pilot understand his management role in conjunction with automation. Automation is a tool to be used, but not blindly relied upon. At all times, flight crew must be aware of what automation is doing, and if not understood, or not requested, reversion to basic modes of operation must be made without immediate analysis or delay. In the man-machine interface, man is still in charge. To quote one research analyst at a recent ICAO conference: ***"Pilots are not robots" - "The pilot who thinks that computers could replace him should be."***

Experience Levels.
Recent FAR regulations have captured the need for Airlines to recognize relative low experience level pilots being rostered together. It is easy for airlines in a rapid expansion phase with new equipment to miss this obvious problem. It is easy to say the training should cope, but in a pressure situation, why have two pilots on their first line flight since checkout rostered together. It is interesting to see a regulatory authority leading the industry with this initiative. The airline is now responsible through computer systems to track its "Green Pilots".

3. Human Factors - Culture.

The position of ICAO is now that HF Training is mandatory (from November 1995) for initial and recurrent training of flight crew of all airlines wishing to operate internationally. Accident rates have stabilized, but are not continuing to reduce. Upwards of 30,000 pilots may be needed worldwide by 2005, and unless the trend down continues, many lives will be lost (however low the statistical rate). Human Factors training is seen as a key to further improvement in Flight Safety. Delta has transferred the reporting lines for CRM/HF to "SYSTEM SAFETY". CRM is moving towards ORM (Organizational Resource Management), which means "embedded" CRM in the whole airline system. Airlines in the US are now regularly using CRM courses which include **Cabin Crew, ATC, Maintenance, and Dispatch Personnel**. Outside the aviation industry, the Medical, Oil, and Nuclear Industries are engaged in the development of CRM programs.

Culture.
Helmreich's (NASA/UT/FAA Crew research Project) latest findings, taken from a large data base of research on multi-cultural flight decks, indicate that pilot culture (ethnic) represents a factor **10 X as relevant** to effective flight management as any other factor (such as experience, and background). **Attitudes and perceptions stemming from cultural perspectives** divide the "Anglo-Western" (individualistic) pilot groups, from the Asian (group-centred) pilot groups. Deference, "power-distance", and "face", are all factors which, in various measures, can hinder effective flight management (specifically CRM). Some positive results are noted when Asian pilots are trained in Western environments, and **CRM Training** does have a large role to play in minimizing the effects of culture on the flight deck.
China is potentially the biggest growth area in the world of aviation for the next 20 years. How can one ignore the problems of 2000 years of social rules, their recent history under communism which has taught them to strongly separate their private thoughts from their public opinions. Face and favour quickly rise to the surface in every day life. Although a fascinating culture it will be one of the greatest challenges to modify CRM programs that can assist in helping crews become more effective the way it has in the western world.
How many airlines in the world provide cultural training for its personnel? There must be some airlines in the Asia, the Middle East, South America and other parts of the world who must be facing the problems of dangerously misaligned communication, and leadership styles.

4. Support Systems

As I have already mentioned, high technology aircraft have big savings in fuel efficiency and maintenance cost. The story does not necessarily end there. The "Electronic" computer driven aircraft has a maturity process to go through. Although Cathay Pacific is happy with the A330/340 combination having a high degree of maturity on the back of the A320 "fly by wire" family, manufacturers are always optimizing the aircraft through software changes. The bigger the fleet the bigger the resources needed to keep up with the changes. Flight Operations and Engineering departments have to maintain close links to understand the state of each aircraft and to cope with the abundance of technical information that is generated. This problem is not new to the military with whole departments devoted to handling these issues but in the econ drive of many of the world airlines it would

appear as a shock that "HIGH TECH" does necessarily mean savings in support manpower and systems. From a maintenance point of view old techniques have to be abandoned in favour of methodically working through a written troubleshooting procedure. Sophisticated support and training equipment is needed. Cabin Crews can no longer depend on the trusty Flight engineer. They have to be trained to be more proactive and not be afraid to reset (reboot) passenger entertainment systems, and to raise their level of awareness to a greater technical level. Again the computer training devices and correct training procedures are essential.

5. External Factors.

This is a separate subject on its own. On a daily basis how many bottlenecks are there in the world where pilots are struggling for levels on congested airways nursing tight fuel policies. Political boundaries, trouble spots with rebel flare-ups in places like Afghanistan, poor ground equipment with several Flight Control Centres struggling together on HF radio (technology over 50 years old) have led to some airlines assessing their safety and investment strategy for solutions. One such solution is FANS (Future Air Navigation Systems) which has the potential to reduce separation with the help of satellite navigation and communication. Its success is dependent on a wider acceptance and investment.

Route strategies are getting longer. Our current studies are focused on a potential New York to Hong Kong aircraft to be delivered in the next 2 to 3 years. There is a greater demand towards the non stop service. Business travelers are prepared to pay a premium. However as we have grown in size as an Ultra Long Haul operator since we first started in the mid eighties so have the size of associated problems. I won't mention the issue of sleep patterns and medical effects to such a learned audience but the PILOT CURRENCY and JOB SATISFACTION are two issues which are close to my heart at present. I look upon the MFF (Mixed Fleet Flying) with a positive safety connotation.

Pilot currency.

Talk to any long haul pilot. What is his biggest complaint? It is the lack of hands on time with an aircraft which is continually doing 14 hour plus sectors. Some of the pilots get very little relief from their main task of "Relief" duties. Hence for the company the tremendous expense of maintaining extra simulators for pilot skill retention.

Job satisfaction.

There are many 'S's when talking on this subject. Apart from Skills and Safety I refer to Satisfaction in relation to the gains of MFF. This obviously follows on, through the sense of feeling on top of the job. Variation in flying stems any boredom and keeps skills and awareness levels high. The "good old days" when some of our pilots flew the DC-4. DC-6, and the Locheed Electra as multi types in the one period produced the height of awareness. It had to be with different fuel systems, switches in different directions and many manuals to remember. This is inappropriate in todays regulatory environment, but technology which creates a common management approach has made multi type flying possible, easy and safe. Cathay Pacific is currently basing some crews at their home base to help with the inflationary pressures of Hong Kong. This is mainly only available to long haul crews. I can see the day with the bedding down of mixed fleet flying, a potential opportunity for basing and far more rostering flexibility due to the positioning to Hong Kong on the A340 and the ability to fly regional services for a week on the A330 before flying the long haul machine back to base. The differing route tasks is a challenge to look forward to, as a pilot flip flops between types. The flexibility is obvious. The second win is for the company in the reduced training costs, and more efficient rostering due to increased daily hour density. The economic advantages seem to on this occasion go hand in hand with safety. This program has commenced with much enthusiasm.

Aircraft Sales.

There is no control. Almost anyone can set up an airline and purchase aircraft from other companies or through complex leasing organizations. The requirements and control of State Authorities throughout the world have been known to vary. This must be of concern to some of the large manufacturers as its reputation inevitably suffers with a hull loss that bears its name. Some of the worlds leading aircraft builders have recognized this and are offering help with support for pilot training and maintenance.

Conclusion.

The selling point of new aircraft is their highly-advanced technology. This however means that they are, by nature, complex machines which require careful handling and strict adherence to their operational philosophy. An airline that flies these aircraft must recognise this and put in place appropriate resources and training. Procedures that have been developed to handle earlier, simpler types of aircraft must also be reviewed and brought up to date.

It is easy to get caught up in the web of cockpit design issues which bombard us daily in technical magazines. These issues are often ruthlessly used to seek marketing advantages. There never has been the perfect flight deck. Airlines must focus their efforts on a committment to **Safety** through a **Systems Approach.** This committment lies in the right Training systems, Communication, Support Systems and Research.

When airline management is considering efficiency, it is best to remember that :

"<u>An ACCIDENT is the ultimate inefficiency</u> ".

CURRENT NEUROLOGICAL PERFORMANCE ISSUES IN ARMY ROTARY-WING OPERATIONS

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1. SUMMARY

Modern rotary-wing military operations present unique challenges that demand optimal neurological performance of the aviator. Tactics unique to Army aviation can be particularly demanding, but many problems plague rotary-wing aviators in general.

Helicopters classically require more attentional resources to control than do fixed wing aircraft; modern helicopters now present the aviator with complex computer systems to simultaneously master. Additionally, the living environment and flight environment inflict unique stresses on rotary-wing aviators--missions are mounted from unimproved field sites, frequently into oppressive thermal conditions that may persist throughout the mission. Nap-of-the-earth flying under night vision devices demands unerring cognitive and sensorimotor performance. Recent downsizing and changing tactics require the distant projection of force--rapid deployment of small and versatile fighting units--with the attendant hazards of sleep deprivation and circadian desynchronosis.

It is likely that improving the quality of information presented to the aviator would reduce workload and the number of accidents due to disorientation. These enhancements could take the form of improved night vision systems, better instrument displays, 3D audio systems, etc. However, high priority should be given to developing and fielding guidance for aircrew work/rest cycles in the combat environment. Neurological performance in the face of operational stress would be best maintained via a customized crew endurance plan that competently addresses circadian rhythms, sustained operations, and operational medications.

2. INTRODUCTION

In many ways, rotary-wing pilots are no different than their fixed-wing brethren. All aviators must follow the same rules controlling airspace, for example, and the basic principles of aerodynamics apply regardless of aircraft type. Nonetheless, there are aspects of helicopter flight that are indisputably unique (particularly in the military), that place exceptional cognitive and psychomotor demands on the rotary-wing aviator.

The neurological stresses and requirements of the modern helicopter pilot are unique in many ways too numerous to list (1-3); only a few important points will be made here. First, the main reason that ground commanders depend on helicopters on the modern battlefield is the ability to hover. Hovering requires the pilot to maintain an awareness of the world immediately to his rear, an aspect of orientation that is different from the fighter pilot "checking six," which is more a focal visual task than a spatial awareness. Second, it is generally acknowledged that a typical rotary-wing flight requires more attention and work from the pilot than the average fixed-wing flight--mostly due to the constant control inputs required of all four limbs, and the fact that hovering is still primarily a visual task. Third, the Army mission requires flying throughout a variety of hostile and varied environments, ranging from nap-of-the-earth desert operations to nighttime landings on the heaving deck of a ship. Finally, the Army rotary-wing combat aviator lives under severe field conditions that invariably take a heavy toll--poor sleep, dehydration and fatigue are frequently the norm.

The unique capabilities of the helicopter have made it a most effective weapons system, resulting in these special demands being placed on today's Army aviator. These demands represent a unique challenge to cognitive and psychomotor performance. Today, as the U.S. Army finds itself in a era of shrinking resources, the mission becomes even more demanding. We are confronted with a variety of new issues that, in various ways, test the aviator's neurological system. These will be discussed in two categories: First, those issues related to new equipment, and second, those related to new demands on human performance.

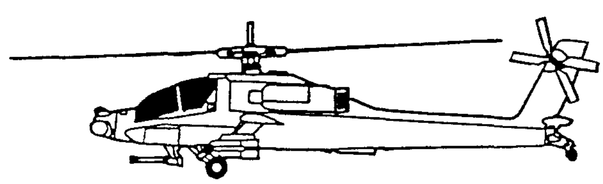

Figure 1. The AH-64A Apache helicopter.

3. EQUIPMENT

3.1 Aircraft

New technology and a changing threat require that aviation equipment be continually updated and upgraded. Human factors challenges occur as a result of new aircraft entering the fleet, as well as by upgrades to existing aircraft. For example, the AH-64 Apache helicopter (Figure 1) presented many aeromedical challenges (discussed below) when it was introduced several years ago. The next helicopter scheduled for acquisition by the U.S. Army is the RAH-66 Comanche helicopter (Figure 2); considerable effort is being spent by both the contractor and the Government to eliminate human factors problems prior to Comanche delivery over the next few years.

Paper presented at the Aerospace Medical Panel Symposium on "Neurological Limitations of Aircraft Operations: Human Performance Implications", held in Köln, Germany from 9-12 October 1995, and published in CP-579.

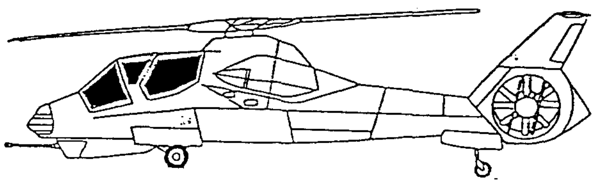

Figure 2. The RAH-66 Comanche helicopter.

Upgrades to existing aircraft can also create new challenges. When the OH-58A fleet was upgraded to OH-58D, the extensively redesigned cockpit included multifunction displays (MFDs) and a mast-mounted thermal imaging system--new technologies for OH-58A pilots. Currently, the U.S. Army is testing the upgrade to the AH-64A attack helicopter, the AH-64D Longbow. This advanced helicopter will feature a completely redesigned cockpit and visionics system. Modernizing older aircraft cockpits inevitably involves extensive changes in displays and software capability.

3.2 Displays and Software

Previous experience with the AH-64A and OH-58D has shown that while modern "glass cockpit" displays certainly streamline the instrument panel, poor hardware or software design actually can increase pilot workload rather than reducing it. For example, changing radio frequencies using an MFD can easily involve more steps than the same task using an old-fashioned dedicated knob. It is critical that these problems be identified early in the design process, as it is extremely expensive to change a design once accepted.

3.3 Personal Equipment

This final category of equipment issues includes all the gear that is attached to the pilot during flight. Not surprisingly, this is a frequent source of comment from aircrew. Since personal equipment is usually less expensive than aircraft components, there is a greater tendency to change or add items every few years, with little thought given to integration with the existing ensemble.

One type of personal equipment that has attracted attention is night vision devices (NVDs). The two basic technologies employed in NVDs are image intensification, as in night vision goggles (NVGs), and thermal sensing, as in forward-looking infrared (FLIR) devices (4-5). While these devices allow flight in conditions that would otherwise be impossible, they present the pilot with a degraded visual image, compared to daytime conditions. Although these technologies are different, the sensory limitations are similar (Table I).

Table I. Comparison of Night Vision Devices (6)

Characteristic	NVG	FLIR
Best Acuity	20/40	20/50-60
Magnification	1x	1x
Field of View (deg)	40	30 x 40
Weight (lbs)	5.9	4.0

Note: NVG = Aviator's Night Vision Imaging System (ANVIS) with counterweight. FLIR = Pilot's Night Vision System (PNVS) from AH-64 aircraft.

Aircraft incidents have occurred as a result of faulty integration of NVGs into existing cockpits (6). Most varieties of NVG are extremely sensitive to red light, and have "shut down" in flight after orange/red instrument panel warning lights were activated. While these instances of sudden sensory deprivation are rare events, they should be entirely preventable.

The AH-64 Apache helicopter is equipped with a thermal sensor on the nose turret of the helicopter, which provides an image that is displayed on the pilot's helmet display unit (Figure 3). This display arrangement has created a number of interesting issues related to visual perception (5-6). For example, because the display is monocular, there are potential problems with binocular rivalry, lost stereopsis, and eye dominance.

Figure 3. The AH-64 Integrated Helmet And Display Sighting System (IHADSS) (5).

Further, because the display (and the pilot's head) is set back several feet from the sensor on the aircraft nose, the pilot experiences a potentially disorienting parallax effect. It is worth noting, however, that Apache pilots rarely complain about the foibles of the visual display--it is simply considered a matter of training. In fact, Apache pilots are nearly unanimous in preferring a monocular display to a biocular design.

From a user's perspective, equipment problems are a source of irritation and concern, but there is seldom anything to be done. By the time the user detects a problem, it is very difficult to effect change (there are notable exceptions), and programs and money are controlled at a much higher level. After all, the military aviator is conditioned to fly with the designated equipment to execute the designated mission. Solutions to human performance issues or crew rest problems are frequently more controllable by (and therefore of greater interest to) the operational aviator.

4. HUMAN PERFORMANCE

Pilot skill and ability can be compromised by equipment problems (as discussed above), or tactical factors. High intensity combat leads to sustained operations and sleep deprivation; night operations predispose to shift lag; and a strategy to project force around the world carries with it the burden of jet lag. Taken together, these factors can severely affect aviator performance.

Although the scientific literature abounds with research results that have practical application, precious little has been provided to the military planner regarding soldier performance. Many effective fatigue countermeasures could easily be implemented in field conditions at little or no expense, if the user were convinced of their benefit. For example:

4.1 Coping With Sleep Deprivation

When confronted with a continuous operations scenario, field commanders and planners could benefit from current knowledge regarding the scheduling of naps--the length, timing and frequency of the nap are important factors to consider. Sedatives and stimulants have been studied both in the laboratory and in combat, and can be safely employed when all else fails (2).

4.2 Coping With Circadian Desynchronosis

Less familiar are available coping strategies for jet lag or shift lag. Good practical information is currently available describing a variety of measures that can speed adaptation to a new work/rest cycle (7). Properly timed light exposure, for example, can dramatically accelerate adjustment of the circadian clock.

5. CONCLUSION

Aircrew neurological performance is affected by both aviation equipment and tactics. Solutions to equipment problems are long-term and lie in careful design and integration. Solutions to many military human performance problems are short-term and involve information dissemination and continuing aeromedical research.

Neurological performance in the face of operational stress would be best maintained via a customized crew endurance plan that competently addresses circadian rhythms, sustained operations, and operational medications. To this end, the U.S. Army Aeromedical Research Laboratory is currently preparing a guide for leaders that addresses many of the currently available techniques to maintain aviator performance in combat.

DISCLAIMER

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FATIGUE AND PERFORMANCE IN THE AIR TRAFFIC CONTROL ENVIRONMENT

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SUMMARY

Air traffic control (ATC) is a complex system in which controllers are faced with many of the human factors challenges posed to personnel in safety-related occupations. This paper focuses on the Civil Aeromedical Institute's (CAMI's) research on shift work-induced fatigue as one factor influencing controllers' performance. Many FAA controllers work relatively unique counterclockwise, rapidly rotating shift schedules. The research presented here was conducted in both laboratory and operational environments. Representative data from three studies are presented on characteristic sleep and performance patterns from controllers and non-controllers working specific rapidly rotating schedules. Problem areas, coping strategy and countermeasures development, and implementation research are discussed.

1. INTRODUCTION

Air Traffic Control (ATC) is a complex system in which controllers are faced with many of the human factors challenges posed to personnel in other safety-related occupations. Performance can be affected by such internal factors as sleep deprivation and circadian rhythm desynchronosis, and external factors, such as working environment, weather conditions, and traffic workload. For the past several years, the Federal Aviation Administration's (FAA's) Civil Aeromedical Institute (CAMI) has conducted a research program designed to develop countermeasures to fatigue resulting from these factors. This presentation focuses on the research on shift work as one factor influencing Air Traffic Control Specialists' (ATCSs') fatigue, sleep patterns, and performance.

Many FAA controllers work relatively unique counterclockwise, rapidly rotating shift schedules. Rapidly rotating schedules involve working only two or three consecutive days on the same shift. The counterclockwise rotation is an advancing schedule in which shift start times begin progressively earlier throughout the schedule. This rotation compresses a work week such that employees have a longer period of time off between compressed schedules than they would on straight shifts. Because of this, ATCSs report that they prefer these schedules (1). Advancing schedules, however, are generally not recommended by shift work researchers because of the potential for sleep loss, circadian rhythm disruption, and possible resultant fatigue or performance decrements (2-3). While there has been much discussion in the literature about the most acceptable shift rotation (4-5), there is little empirical data to support decision making (6). In the *Bulletin of European Shiftwork Topics*, Wedderburn (7) cited several researchers in recommending that no more than two to four night shifts should be worked in succession. The ATCS shift schedules minimize employee exposure to the night shift, and have been used successfully in ATC facilities for several decades (8).

The current program was developed in conjunction with increased interest from the Air Traffic Service in alternate work schedules and sleepiness on the night shift. As an applied research program, the goal was to develop products and tested strategies for assisting management and employees in dealing with the challenges of shift lag and fatigue. A three-phase research approach was adopted to systematically achieve these goals: 1) problem assessment within the specific operational context, 2) countermeasure development and evaluation based upon the empirical problem assessment, and 3) implementation and assessment of the countermeasures as they are deployed to the field.

The purpose of the present paper was to consolidate findings of three studies from the problem assessment phase and examine the lessons learned about these particular schedules. The first study, Fatigue and Performance, was a laboratory-based study designed to investigate the relationship between working the "2-2-1", a specific counterclockwise, rapidly rotating schedule, and performance, circadian rhythms, physiology, stress indicators, and sleepiness in two age groups (9-10). The second study, 10-hour Work Day, compared performance of ATCSs working 10-hour vs. 8-hour shift schedules (11). This was conducted in the field. Finally, the third study, Sleepiness on the Midnight Shift, investigated the problem of sleepiness on the night shift in ATCSs in a field facility, including information about adaptation to shift work, sleep, and activity patterns, diet, exercise, and ratings of sleepiness (12).

These three studies gave us the opportunity to examine four shift schedules worked in the operational environment. Three were counterclockwise, rapidly rotating schedules, the 2-2-1 (two afternoons, two early mornings, and one night shift), the 2-1-2 (two afternoons, one mid-day, and two early mornings), and the 10-hour (two afternoons and two day/early morning shifts). The fourth was a straight early morning schedule. A fifth schedule of straight days was examined in comparison to the 2-2-1 in the laboratory study. For this presentation, we will focus on the results from the sleep and performance measures.

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2. APPROACH

2.1 Studies

The three studies reviewed here were based in both the laboratory and operational environments. Each examined measures of sleep, and two studies measured performance.

2.1.1 Study 1. Fatigue and Performance (Laboratory). The first study was designed to examine the effects of working the 2-2-1 schedule on sleep, performance, and circadian rhythms in two age groups. For this study, twenty male subjects were selected for an "older" group (age=50-55 years, n=10) and a "younger" group (age=30-35 years, n=10). Although they were not ATCSs, subjects were matched on characteristics of the ATCS population including medical status and cognitive abilities. Data on sleep times, duration, and quality were collected by self-report in daily logbooks (9). Performance measures were collected from the CAMI Multiple Task Performance Battery (MTPB) (10). The MTPB tasks included static and dynamic monitoring and information processing tasks involving mental arithmetic, complex visual discrimination, and problem solving. The tasks were variously combined into a two-hour protocol that resulted in varied work loads across the two hours. The MTPB provided a motivating synthetic work environment in which subjects worked simulated eight hour shifts, completing 3 two-hour MTPB sessions per shift. During the protocol, subjects worked three work weeks in the MTPB laboratory comprised of 1) one week of day shifts (0800-1600), 2) one week of the 2-2-1 schedule (1600-2400; 1400-2200; 0800-1600; 0600-1400; 2400-0800), and 3) one week of day shifts (0800-1600). This provided an A-B-A design in which performance on a straight day shift schedule could be compared to performance on the 2-2-1.

2.1.2 10-hour Work Day (Minneapolis): This study was conducted at the request of the FAA Air Traffic Service following an agreement to implement 10-hour work days on a trial basis. The purpose of the study was to compare measures of performance on a computerized task battery and alertness of ATCSs working 10-hour shift schedules versus their more traditional 8-hour 2-2-1 schedules. Data were collected from 52 volunteers at the Minneapolis Air Route Traffic Control Center (ARTCC). Of these, 26 ATCSs worked the 2-2-1 schedule and 26 worked four 10-hour days. Performance data were collected using the National Institute of Occupational Safety and Health (NIOSH) Fatigue Test Battery. In addition to the performance tasks, subjects completed questions about sleep, somatic complaints, and mood. Three test sessions were administered during the course of each work day. The first session was completed at the beginning of the work day. The second session was conducted two hours prior to the end of the work day (at the end of 6 hours for the 8-hour shift workers and at 8 hours for the 10-hour shift workers). The final session was administered at the end of the work day.

2.1.3 Sleepiness on the Midnight Shift (Miami). This study was conducted at the request of the Miami enroute center's management and labor team in response to a concern about sleepiness on the night shift. Twenty-four of 95 volunteers from the Miami ARTCC completed a full week of log book entries for one of three schedules, the 2-2-1, the 2-1-2, or straight early morning shifts. Twenty-three were ATCSs and one participant was from the airway facilities work force. Sleep pattern data were collected in the log books on a daily basis and were checked periodically by on-site CAMI researchers. Five subjective measures of sleep and sleepiness were analyzed for each of the three schedules: 1) Asleep Time, 2) Awake Time, 3) Total Sleep Time, 4) Sleep Quality Ratings, and 5) Stanford Sleepiness Scale (SSS) ratings (13).

2.2 Schedules

Table 1 presents sample schedules and the number of hours off duty between shifts. Five schedules were examined within the three studies. As noted above, these were the 2-2-1, the 2-1-2, 10-hour, straight early mornings (0600-0759 start time), and straight day shifts (0800 start time).

The 2-2-1 schedule requires ATCSs to work two afternoon shifts, followed by two early morning shifts, and finally, a night shift. In this schedule, a 40 hour work week is completed in 88 hours, as opposed to 104 hours required on a straight-day schedule. The 2-2-1 results in 80 hours off between work weeks, compared to 64 hours on straight days. The transitions from the afternoons to mornings and from the mornings to the night shift involve "quick-turn-arounds" with as few as eight hours off between shifts. The 2-1-2 schedule involves working two afternoons, followed by one mid-day, and two early morning shifts. This schedule does not contain a night shift and includes two quick-turn-arounds of 12-hours each. The 40 hour week is completed in approximately 96 hours, and the employee has 72 hours off between work weeks. The 10-hour schedule was implemented in a counterclockwise, rapidly rotating fashion that involved two afternoons followed by 2 day/early morning shifts. This 10-hour schedule was completed in approximately 72 hours with 96 hours off between work schedules.

2.3 Measures

2.3.1 Sleep Measures. Subjective sleep measures were collected in each of the three studies. Total Sleep Time (TST) will be reported from each of the studies. Asleep and Awake Times Data will be reported from the laboratory and Miami studies. Data for these two studies were collected with daily log books modified from those developed by the National Aeronautics and Space Administration (NASA) (14). Volunteers were asked to discriminate between "in bed" and "asleep" times and between "awake" and "arise" times. Long awakenings during the sleep period (30 minutes or greater) were subtracted from the TST. The laboratory data were verified using a wrist activity monitor (Vitalog model HMS-5000, Redwood City, California). Sleep data in the Minneapolis study were collected during the first performance session on the computer. Subjects were asked to indicate their time of retiring, arising, sleep latency, and number of awakenings.

2.3.2 Performance Measures. Two performance batteries were used in two of the studies reviewed here: 1) the Multi-

Table 1
Work Schedules

	Day 1	Day 2	Day 3	Day 4	Day 5
2-2-1 Schedule					
Laboratory					
Shift Type	A	A	D	E	N
Sample Schedule	1600-2400	1400-2200	0800-1600	0600-1400	2400-0800
Hours off between Shifts	14	10	14	10	
Field					
Shift Type	A	A	E	E	N
Sample Schedule	1430-2230	1330-2130	0700-1500	0600-1400	2230-0630
Range of Start Times	1330-1600	1000-1600	0600-0800	0600-0620	2200-2400
Range of End Times	2130-2400	1800-2400	1400-1600	1400-1420	0600-0800
Hours off between Shifts	16	8	16	8	
2-1-2 Schedule					
Field (Miami)					
Shift Type	A	A	M	E	E
Sample Schedule	1430-2230	1330-2130	1030-1830	0700-1500	0700-1500
Range of Start Times	1330-1500	1250-1400	0955-1100	0630-0700	0600-0745
Range of End Times	2130-2400	2250-2300	1755-2000	1430-1600	1400-1545
Hours off between Shifts	16	12	12	16	
10 hour Schedule					
Field (Minneapolis)					
Shift Type	A	A	D	E	
Sample Schedule	1400-2400	1200-2200	0800-2000	0600-1600	
Range of Start Times	1200-1400	0600-1400	0600-1000	0600-0700	
Range of End Times	2200-2400	1600-2400	1600-2000	1600-1700	
Hours off between Shifts	12	10	10		
Straight Early Morning Schedule					
Field (Miami)					
Shift Type	E	E	E	E	E
Sample Schedule	0730-1530	0700-1500	0700-1500	0630-1430	0630-1430
Range of Start Times	0630-1000	0630-0900	0630-1000	0630-0700	0630-0645
Range of End Times	1430-1900	1430-1800	1430-1900	1430-1600	1430-1445
Hours off between Shifts	16	16	16	16	
Straight Day Schedule					
Laboratory					
Shift Type	D	D	D	D	D
Sample Schedule	0800-1630	0800-1630	0800-1630	0800-1630	0800-1630
Hours off between Shifts	16	16	16	16	

E=Early morning shift D=Day shift M=Mid-day shift A=Afternoon shift N=Night shift

ple Task Performance Battery and 2) the NIOSH Fatigue Battery. Tasks in both batteries were selected because they measured basic psychological or cognitive functions relevant to control of complex systems in general, and ATC tasks in particular. The MTPB was a computerized task battery based on a Digital Equipment Corporation MicroVAX II central processor and five TEKTRONIX Model 4125 color graphics workstations, developed by Dr. Henry Mertens at the CAMI (15). Subject response panels were custom designed for subject inputs. The tasks in the battery were as follows: 1) red and green light monitoring, 2) meter monitoring, 3) mental arithmetic, 4) target identification (a pattern recognition task requiring mental rotation), and 5) code lock (a procedural task requiring subjects to decode a sequence of five letters in a left-to-right search pattern and recall the sequence 15 seconds later). The monitoring tasks were considered passive tasks, while the mental arithmetic, target identification and code lock were characterized as active tasks. Raw scores included percent correct and response times. Three levels of performance scores were assessed. For purposes of this paper, composite scores combining performance on all tasks into one of three (total composite (TC), passive composite (PC), and active composite (AC)) were reported.

The NIOSH Fatigue Test Battery was developed specifically for applications in field studies with employees working different shift schedules (16). Three tests were selected from the battery for administration: choice reaction time, mental arithmetic, and grammatical reasoning. Scores included response time, number of errors, and number of arithmetic problems attempted.

3. RESULTS

All three studies reviewed here employed mixed model designs with both between-groups factors (schedule type and/or age) and within-subjects repeated measures factors (day of the study and/or session). A summary of the findings from planned multiple comparisons for both the sleep and performance variables investigated in these studies is presented below. Alpha was set at .05 for each of the studies. More detailed study findings were reported in the original publications.

3.1 Sleep Data

3.1.1 Total sleep time (TST). A summary of the descriptive statistics for TST for each of the schedule types investigated in the three studies is presented in Table 2.

3.1.1.1 Within-subject Comparisons. In all three studies, some variation of the 2-2-1 schedule was investigated. All of these showed a fairly characteristic decline across the work week, with the greatest TST before the afternoon shifts, shorter TST before the day and early morning shifts, and the shortest TST before the midnight shift. The sleep before the midnight shift was taken during the day on the quick-turnaround between the morning shift and the midnight shift. In all three studies, this sleep period was significantly shorter than for the other days of the week. In the Miami study, TST before both of the early morning shifts was significantly shorter than before either of the afternoon shifts. This finding was evident in the 10-hour study, but was not apparent in the laboratory study. Although each study displayed a fairly characteristic declining TST pattern, the data from the laboratory study did reveal a slight (but statistically non-significant) departure from the field studies on the fourth day of the work week. On this day, average TST increased from 5.8 hours to 6.6 hours.

Unusual schedules which were not repeated in any of the studies were the 2-1-2, 10-hour, straight early morning, and straight day schedules. A similar pattern of decline in TST as found in the 2-2-1 schedule was also found in the 2-1-2 schedule. TST was longest before the two afternoon shifts and one mid-day shift and shortest before the two early morning shifts. A significant decline before the first 10-hour afternoon shift and the last 10-hour early morning shift was also detected. No differences were found across the straight early morning shifts in the Miami study or across the straight day shifts in the laboratory study.

3.1.1.2 Between-group Comparisons. Because three schedule types were represented, the Miami study provided the best opportunity to compare sleep patterns between schedules. There was no difference in TST between the sleep periods before the afternoon shifts in either the 2-2-1 or 2-1-2 schedules. There was also no difference in TST between the sleep periods before the early morning shifts in either the 2-2-1, 2-1-2, or straight early morning schedules. TST for both afternoon shifts in the 2-2-1 and the first afternoon shift in the 2-1-2 were significantly longer than the respective early morning shifts in the straight day schedule. TST for the 2-1-2's mid-day shift was significantly longer than the early morning shifts in both the 2-2-1 and the straight early morning schedules. Finally, TST before the midnight shift in the 2-2-1 schedule was significantly shorter than before the early morning shifts of the 2-1-2 and straight early morning schedule. On average, over the course of the work week, the 2-1-2 schedule resulted in significantly longer TST (M=7.0 hours) than either the straight early morning schedule (M=6.0 hours) or the 2-2-1 schedule (M=5.7 hours).

3.1.2 Asleep and Awake Times. Both the laboratory and Miami studies examined the changes in asleep and awake times over the course of the shift schedules. A summary of the descriptive statistics for asleep and awake times for each of the schedule types investigated in these two studies is presented in Table 3. Comparisons of asleep and awake times are made from one sleep period to the next.

During the 2-2-1 work week in the laboratory study, asleep time was significantly shifted as follows: 1) an approximate 2-hour delay of the sleep prior to the second afternoon shift as compared to the first, 2) an approximate 2-hour advance of the sleep prior to the first day shift compared to the second afternoon shift, and 3) an approximate 2.5-hour advance of the sleep prior to the second day shift compared to the first. In addition, the asleep time for the daytime sleep prior to the midnight shift was also significantly earlier than the previous sleep period because it occurred during the day. In compari-

Table 2
Means and Standard Deviations for
Total Sleep Time on ATCS Shift Schedules

	Day 1	Day 2	Day 3	Day 4	Day 5
2-2-1 Schedule					
Laboratory					
Shift Type	A	A	D	E	N
Mean (hours)	7.6	6.4	5.8	6.6	3.7
SD	1.5	1.5	0.9	1.0	1.6
Field (Miami)					
Shift Type	A	A	E	E	N
Mean (hours)	8.3	7.7	5.1	5.1	2.4
SD	1.0	1.1	0.7	0.8	0.8
Field (Minneapolis)					
Shift Type	A	A	E	E	N
Mean (hours)	8.1	7.9	6.0	5.8	3.6
SD	2.0	1.4	1.2	1.6	1.8
2-1-2 Schedule					
Field (Miami)					
Shift Type	A	A	M	E	E
Mean (hours)	8.2	7.3	7.6	6.0	5.9
SD	1.7	1.5	0.7	0.8	0.7
10 hour Schedule					
Field (Minneapolis)					
Shift Type	A	A	E	E	
Mean (hours)	8.1	7.2	7.0	5.7	
SD	1.7	1.7	1.4	1.1	
Straight Early Morning Schedule					
Field (Miami)					
Shift Type	E	E	E	E	E
Mean (hours)	6.2	6.3	6.2	5.8	5.6
SD	1.3	1.3	1.0	1.0	1.1
Straight Day Schedule					
Laboratory					
Shift Type	D	D	D	D	D
Mean (hours)	6.5	7.0	6.7	6.8	7.0
SD	1.2	1.1	0.8	0.8	1.2

E=Early morning shift D=Day shift M=Mid-day shift A=Afternoon shift N=Night shift

Table 3
Means and Standard Deviations for
Asleep and Awake "Clock" Times on ATCS Shift Schedules

	Day 1	Day 2	Day 3	Day 4	Day 5
2-2-1 Schedule					
Laboratory					
Shift Type	A	A	D	E	N
Asleep Time	0007	0158	0005	2140	1651
SD	1.6	0.8	0.8	1.1	1.4
Awake Time	0740	0833	0600	0423	2027
SD	1.8	1.9	0.5	0.4	2.0
Field (Miami)					
Shift Type	A	A	E	E	N
Asleep Time	0015	0033	0022	2348	1621
SD	0.9	0.7	1.0	0.8	1.3
Awake Time	0850	0817	0540	0457	1843
SD	1.6	1.3	1.0	0.5	1.1
2-1-2 Schedule					
Field (Miami)					
Shift Type	A	A	M	E	E
Asleep Time	0015	0035	0005	2340	2330
SD	1.3	1.0	0.3	0.8	0.7
Awake Time	0828	0754	0744	0540	0524
SD	1.6	1.4	0.7	0.5	0.5
Straight Early Morning Schedule					
Field (Miami)					
Shift Type	E	E	E	E	E
Asleep Time	2320	2245	2250	2243	2309
SD	1.4	0.8	0.6	0.6	0.8
Awake Time	0534	0510	0504	0434	0447
SD	1.0	1.3	0.9	0.7	0.4
Straight Day Schedule					
Laboratory					
Shift Type	D	D	D	D	D
Asleep Time	2300	2236	2300	2251	2251
SD	1.0	1.0	0.9	0.7	1.2
Awake Time	0539	0546	0546	0546	0556
SD	0.9	0.7	0.5	0.6	0.6

E=Early morning shift D=Day shift M=Mid-day shift A=Afternoon shift N=Night shift

son, asleep times before the first four shifts of the 2-2-1 schedule in the Miami study were not significantly different from one sleep period to the next. Only the daytime sleep before the midnight shift was significantly advanced compared to the previous sleep period. Within both the 2-1-2 and straight early morning schedules in the Miami study, no significant differences in asleep time were found from one sleep period to the next. ATCSs on the early morning shifts appeared to have consistently earlier asleep times than employees on the other two schedules.

Awake times during the 2-2-1 work week in the laboratory study were shifted similarly to the asleep times: 1) an approximate 2.5-hour advance of the awake time for the sleep prior to the first day shift compared to the second afternoon shift and 2) an approximate 1.5-hour advance for the sleep prior to the second day shift compared to the first. In addition, the awake time for the daytime sleep prior to the midnight shift was significantly earlier than the previous sleep period because it occurred during the day. Unlike asleep times during the 2-2-1 work week in the Miami study, awake time was significantly advanced between the second afternoon shift and the first day shift. Likewise, awake time was advanced on the daytime sleep before the midnight shift. Within the 2-1-2 schedule in the Miami study, awake time was advanced as follows: 1) by approximately 0.5 hour for the sleep prior to the second afternoon shift compared to the first and 2) by approximately two hours for the sleep prior to the first early morning shift compared to the mid-day shift. There were no differences in awake time across the week for the early morning shift schedule.

3.2 Performance

3.2.1 The Multiple Task Performance Battery. A 2 (age) x 10 (days) x 3 (sessions) MANOVA was conducted to assess the effects of working the 2-2-1 schedule on MTPB performance in the laboratory study. The MANOVA revealed a significant Day by Session interaction for both passive- and active-task composite scores. Planned multiple comparisons revealed that performance on the passive tasks declined significantly over the course of the night shift. Planned multiple comparisons on the active tasks revealed that performance on the night shift was significantly lower than on the previous day shift. Analysis of each of the individual tasks on the MTPB revealed that 1) code lock solution reaction time was slower on the third session of the night shift than on the third session of the previous day shift, 2) code lock solution and recall reaction times were slower on the night shift than on the previous day shift, 3) code lock recall percent correct was lower on the night shift than on the second day shift, and 4) target identification reaction time was slower on the third session of the night shift than on the third session of the previous day shift.

3.2.2 The NIOSH Fatigue Test Battery. Both within- and between-schedule comparisons were conducted to assess the effects of working the 10-hour schedule and the 8-hour 2-2-1 schedule on NIOSH Fatigue Test Battery performance in the 10-hour study. The tasks were analyzed individually by day and session.

3.2.2.1 Within Schedule Comparisons. Differences in computerized test performance identified in this study were generally related to day of the week, session, and day by session interactions. Reaction times slowed from the first day of the week to the last for the choice reaction time task. The final session of the day, however, resulted in the fastest reaction times. The slowest reaction time occurred during the night shift for ATCSs on the 2-2-1 schedule and was approximately 12% slowere than average when compared to the first day of the week. There was a significant day by session interaction on errors for the choice reaction time task, such that errors increased between the first and last session of the day. The effect was more pronounced on the third through fifth days of the week. The average number of errors on mental arithmetic remained relatively stable across the first 4 days of the work week for both schedules; however, the average for the 2-2-1 on the night shift was greater than on the previous days. The number of problems attempted increased across the work week for both schedules. However, on the 2-2-1 schedule the increase only continued until day 3. Days 4 and 5 resulted in fewer attempts. On grammatical reasoning, reaction times generally decreased across the week on the 10-hour shift schedule. On the 2-2-1, reaction times for the grammatical reasoning task were slower on day 3.

3.2.2.2 Between Schedule Comparisons. Comparing the first four days of the work week, no differences in performance were identified in this study between ATCSs working the 8-hour 2-2-1 schedule and the 10-hour schedule.

4. DISCUSSION

CAMI's shift work and fatigue research program was designed to 1) provide an empirical basis for identifying the nature and extent of potential problem areas within the shift schedules worked in air traffic facilities, 2) develop countermeasures and coping strategies, and 3) conduct countermeasure and coping strategy implementation research. Many of the schedules incorporate counterclockwise, rapid rotations of shifts in the schedule. The purpose of the present paper was to examine a body of research conducted within the problem assessment phase concerning sleep and performance to establish a foundation for the identification and development of countermeasures. Based upon these findings, the research program has proceeded into phases 2 and 3 of developing and assessing implementation of countermeasures. From the three studies, we were able to examine five different schedules. Three were counterclockwise, rapidly rotating schedules: the 2-2-1, the 2-1-2, and the ATCS implementation of a 10-hour workday. The other two schedules were straight days and early mornings.

Findings from the sleep data suggest that sleep durations on the counterclockwise rotations were within the ranges of employees working permanent afternoons and early morning shifts. Tepas and Carvalhais (17) reported mean sleep lengths from survey data from workers in four plastics and rubber industry plants for sleep periods prior to specific permanent

shifts as follows: 1) day shifts=7.24 hours (sd=0.8), 2) afternoon shifts=7.71 hours (sd=1.2), and 3) night shifts=6.8 hours (sd=1.4). Afternoon shifts were worked in both the 2-2-1 and 2-1-2 shift schedules in these studies. Findings indicated that ATCSs achieved the longest sleep periods prior to the afternoon shifts. Average TST for ATCSs on the afternoon shifts ranged from 7.7 to 8.3 hours in both the field studies and from 6.4 to 7.6 hours in the laboratory study.

Early morning shifts significantly reduced sleep in all of the schedule types investigated due to early awake times. All three counterclockwise, rapidly rotating schedules (the 10-hour, 2-2-1, and 2-1-2) rotated into early morning shifts. Folkard (2) suggested that early start times could result in similar sleep debt to that seen for the night shift. This was supported in the Miami study with TSTs ranging from 5.6 to 6.3 hours for employees on straight (non-rotating) early morning shifts. These averages for early morning shifts were even less than the 6.8 hours reported by Tepas and Carvalhais (17) for permanent night shift workers. No sleep loss was observed in the 2-1-2 schedule when ATCSs rotated from afternoons to the midday shift. Thus, the decreased TST in the counterclockwise rotating schedules appeared to be due to the early morning shifts. This resulted in sleep loss toward the end of the work week. Modifying shift start times has been reported to assist in improving sleep for individuals working early morning shift schedules (18). It might be possible to improve the current ATCS rotating schedules by delaying the start times of the early morning shifts, especially prior to rotating into a night shift on a quick-turn-around.

A body of research on the 2-2-1 schedule was reported by CAMI researchers (8, 19). These studies demonstrated a characteristic pattern of declining sleep duration across the course of the week. The shortest sleep duration in the 2-2-1 schedule was obtained during the day before the night shift. Most ATCSs were able to obtain some sleep in the afternoon. Because this afternoon sleep period follows the early morning shift, ATCSs have had some additional sleep within the 24-hour period prior to reporting for the night shift. Many ATCSs also reported sleeping for several hours after the night shift. These patterns were found in both the Miami and Minneapolis studies of the 2-2-1 schedule.

An interesting finding from the field data indicated that ATCSs in the field tended to stabilize asleep times. This was unlike the laboratory study in which subjects advanced their asleep times in anticipation of the early morning shift. Because the counterclockwise, rotating shift schedule has the potential to result in shift lag, stability in the sleep/wake cycle is important, and it appears that employees may maintain stability of asleep times as an adaptive strategy.

Comparing computerized test performance on the four days of 8-hour shifts to the 10-hour shift performance, no significant differences were found. However, the performance data from the laboratory, as well as the Minneapolis studies demonstrated performance decrements on the night shift for the 2-2-1 schedule. These findings point to the potential utility of countermeasures on the night shift to improve alertness and performance.

In summary, review of the body of evidence on ATCS shift schedules revealed the following: 1) sleep loss occurs toward the end of the week on counterclockwise rotating schedules as employees rotate into early morning and night shifts, 2) performance decrements on the MTPB were primarily evidenced on the night shift, 3) performance on the NIOSH Fatigue Test Battery was not found to differ between the 10-hour and the 8-hour 2-2-1 rotations, and 4) straight early morning shifts resulted in as much sleep loss as the counterclockwise rotations.

As the research program advances farther into the phase 2 research of developing potential countermeasures, present findings can assist in deciding on an appropriate focus. A number of countermeasures are being considered for adoption. These include napping, bright lights, melatonin, individual coping strategies, exercise, schedule changes, and a variety of others. Our approach is broadly based to include not only individually-based countermeasures, but also possible changes to the work environment and the employing organization which would assist in reducing shift-related fatigue.

Based upon the findings in these studies, the primary focus has been on developing countermeasures for sleepiness on the night shift, and the secondary focus has been on individual coping strategies. At the request of Miami ARTCC, a study of the effectiveness of napping on the night shift was initiated in 1995 in collaboration with Dr. Carlos Comperatore, at the U.S. Army Aeromedical Research Laboratory (USAARL). In addition, the CAMI and the USAARL developed an educational brochure and training package that was administered to 135 Miami ARTCC ATCSs. While it was well received, an implementation study is required to assess the effectiveness of the program.

The research reported here is part of a larger program assessing the effects of fatigue on performance and involving other Department of Transportation modes. Linkages between the CAMI program and research at the USAARL will continue. In addition, collaboration encompassing work in each of the phases of countermeasure research is underway with NASA Ames and other Department of Defense laboratories.

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ENHANCING NEUROLOGICAL PERFORMANCE IN NAVAL AEROSPACE USS CARRIER GROUND AND SUPPORT OPERATIONS: PRACTICAL CHALLENGES

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SUMMARY
Flight operations aboard an aircraft carrier resemble operations at a busy, land based airport, only compressed into a small space. The flight operational environment is intense, prolonged, and very hazardous. This is especially true for the carrier's flight deck personnel who handle ground and support operations. This paper will discuss the major risk factors affecting flight deck personnel performance, the neurological implications, and practical challenges to enhancing performance.

High workload, sustained operations, heat and cold stresses, wind and rain, neurosensory deficiencies, noise and vibration, as well as acute and chronic injury, emotional and interpersonal problems are all risk factors that can lead to neurological limitations affecting flight deck performance. Fatigue, lethargy, sleepiness, headaches, potential head, neck, and back injuries, as well as decreased visual acuity and hearing, peripheral neuropathies, decreased cognitive, motor, and coping functions are among the potential neurologic problems. These conditions will limit flight deck performance.

These factors lead one to consider a number of efforts that could potentially enhance flight deck performance. Consideration of these presents a number of challenges. How can we better screen and periodically evaluate flight deck personnel for the "right stuff?" Would a formal, more quantitative daily risk assessment and management program enhance overall flight deck performance? How should we address current education and training safety programs to enhance performance? How can we better handle morale issues that affect performance? Finally, potential applications of research findings to enhance neurologic performance in flight deck personnel present unique challenges. For example, should performance enhancing drugs be used, and if so, when and how?

1. INTRODUCTION

Flight operations aboard an aircraft carrier are like flight operations at a busy, land-based airport. However, the angled deck of a United States Nimitz class carrier is only 1000 feet long and 250 feet wide. At peak operations aircraft are being launched every 60 seconds and recovered every 45 seconds. The flight deck operational evnvironment is intense, prolonged, and very hazardous. This is especially true for the carrier's flight deck personnel who handle ground and support operations.

For safety reasons and ease of identification, all personnel working on the flight deck wear different colored shirts, jackets, or vests based on their flight deck jobs and responsibilities. "Yellow shirts" are responsible for overall direction of setting up for aircraft catapults, better known as "cats." Under the directiion of the "yellow shirt," the "green shirts" work intimately with the aircraft as it prepares to launch, first attaching the catapulting devices to the aircraft's nosegear, then insuring proper attachment, and finally insuring proper lineup as the aircraft moves into position for takeoff, a particularly hazardous position for the "green shirt." "Brown shirts," or plane captains, give the final signal for the side deck crew to press the "go" command switch for launch. Significant hazards during this phase, besides actual aircraft contact or ingestion, include jet afterburner blast, heat, and noise. As each aircraft takes off, another is being readied.

Aircraft arrested landings, known as "traps," on the carrier are just as intense as the "cats" for flight deck personnel. Potential hazards are serious. For example, a trap wire may break sending a flailing, uncontrolled wire across the deck fatally injuring anyone in its path. Or, an aircraft may strike the ramp, producing an all-consuming fireball. The "yellow shirts" and "green shirts" working in this area are considered to be at greatest risk among all flight deck personnel. Once an aircraft "traps" and taxies to the parking area, it is the responsibility of the "brown shirt" to chain the aircraft to the deck. "Brown shirts" are typically seen carrying the necessary heavy chains around their necks. The potential for neuromuscular problems becomes quite obvious.

Ground support of carrier air operations also includes refueling aircraft by "purple shirts," and handling ordnance by "red shirts." Furthermore, there are numerous behind-the-scenes personnel performing many other necessary tasks, each with its own set of potential hazards. For example, those responsible for overall monitoring of operations are under significant stress, while the responsibility for adjusting catapult power settings is done in a relatively closed, cramped, and hot space. Flight operations usually begin at dawn and may not stop until well after dark. Air operations may also occur in less than ideal weather conditions, making ground support of carrier air operations even more hazardous.

2. RISK FACTORS

Unlike aircrew, flight deck personnel don't experience G-forces or hypoxiawhich limit performance, but there are a number of factors which dolimit flight deck performance. First, as already described, workload is intense. Each evolution involves working in close proximity to moving aircraft and jet engine air intakes and exhausts. Workload may involve lifting and moving heavy materials or parts, and requires a constant high level of situational

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awareness. Second, during wartime or with intense training exercises, sustained flight operations will begin early in the morning and may go well into the night--sometimes all night. Flight deck personnel are expected to perform from the time operations begin until the flight deck is secured. Unlike their civilian couterparts, carrier flight deck personnel are presumed to be able to work twenty-four hours a day, seven days a week if necessary. Third, environmental heat, cold, noise, vibration, darkness, and inclement weather are all adverse stresses that place flight deck personnel at increased risk. Fourth, limited visual acuity and suboptimal hearing ability due to noise and personal noise attenuation devices are neurosensory factors that may affect performance. Fifth, both acute and chronic injuries will limit or preclude performance. With limited numbers of qualified flight deck personnel on a deployed carrier, the workload increases for remaining crewmembers when one member is not able to perform due to an injury or illness. Finally, degradation of performance may occur as a result of life stresses that come from long deployments away from home, from interpersonal conflicts, from lack of social support, family separation, cramped living quarters, and from lack of privacy and other personal privileges.

3. NEUROLOGICAL IMPLICATIONS

The above risk factors have significant neurological performance implications. High workload may lead to fatigue, sleepiness, potential head injury, and headaches. Each of these will be reflected in degraded flight deck performance. Sustained operations will eventually lead to fatigue, sleepiness, complacency, decreased motivation, channelized attention, and overall decreased situational awareness. These, in turn, will potentially lead to injuries, and overall mission degradation. Environmental stresses such as heat and cold can result in reduced alertness, movement retardation, cognitive impairment, headaches, and heat illnesses, making performance difficult if not impossible. Inclement weather may reduce visibility and visual acuity thereby reducing situational awareness and performance. The constant vibration experienced in the air operations environment can also lead to significant fatigue.

Neurosensory deficits, such as impaired visual acuity and reduced hearing ability can lead to significant degradation in situational awareness and a mishap. For example, in a recent aircraft mishap, the fact that the flight deck "green shirt" was not wearing his prescribed glasses while hooking a F/A 18 up for launch contributed to a faulty catapult and subsequent unsuccessful launch and crash of the multi-million dollar aircraft.(1) Reduced visibility from darkness can also lead to decreased situational awareness. In a recent flight deck mishap after dark, a spotter was sucked up into an A-6's jet engine intake. It was several minutes after engine shutdown before anyone became aware of the actual problem. Remarkably, the individual received only minor injuries.(1) Likewise, reduced hearing and fatigue from noise and the use of hearing protection devices may lead to degradation in performance by reducing situational awareness.

In his study of injuries sustained by U.S. flight deck personnel from 1977-1991, Shappell reported that the most common neurological injuries were, in decreasing frequency, spinal fractures, skull fractures, and brain concussions.(2) The current annual injury rate among flight deck personnel for reportable injuries is between 30-50 per 100,000 carrier landings. Circumstances in which the most serious injuries occurred included falling from heights, and being struck by , caught in, or run over by a part of an aircraft. Overexertion may lead to various neuromuscular pain syndromes, e.g. strains and sprains, and chronic low back pain. Anecdotal evidence indicates that the incidence of repetitive motion problems, such as carpal tunnel syndrome, are increasing. All of these neurological insults will adversely affect overall flight deck performance, either directly by limiting the performance of the injured individual, or indirectly by shifting the workload to others who are already overworked. Furthermore, injured personnel cannot be easily replaced while the carrier is deployed.

Finally, increased life stressors may lead to significant neuropsychiatric dysfunction. Cognitive and motor function may become impaired. Overly strained coping mechanisms may lead to anxiety or depression and to a variety of somatoform problems such as headaches, pain syndromes, and gastrointestinal complaints. Weigmann and McKay report that the harsh working conditions, quality of life, and management/organizational structure in which carrier flight deck personnel work and live are directly related to psychological and physiological well being, and directly related to the number of injuries and illnesses.(3) On any single day of operations as many as 42% of "green shirts" reported feeling exhausted, tense, or under great stress. Fifty-five percent of "yellow shirts" reported having low back pain, and up to 38% of all flight deck personnel reported having headaches. These problems will obviously limit individual and overall flight deck performance.

4. CHALLENGES

Consideration of the above risk factors and the neurologic implications lead to a number of practical challenges to enhance performance.

Improving the fitness of personnel entering flight deck work would probably enhance performance and safety. Improving individual visual acuity, screening for better baseline hearing, and insuring optimum physical height, weight, and strength needed in the flight deck environment would all be beneficial. Current entrance physical standards and periodic evaluation standards for flight deck personnel are not very stringent.(4) In their study, Weigmann and McKay found that those flight deck individuals who were "morning types" reported less strain in the carrier flight deck environment than those individuals who were "night owls."(3) Morning types are individuals who prefer to go to bed early and rise early in the morning. Night owls are those who have trouble waking up in the morning and prefer to stay up late at night. This finding suggests that psychological testing to screen in "morning types" might enhance performance. However, before current physical standards can be changed or additional screening tests be implemented, line as well as aeromedical leaders must be convinced that such changes would be productive. Thus, significant challenges here involve leadership, education, and training of supervisors, commanders, and aeromedical leaders.

Daily assessment of fitness-for-duty might enhance performance.

The use of daily qualitative risk assessment checklists and of quantitative screening devices might enhance performance. The FIT™ test, a pupillary reaction test for neurological function, or the Critical Tracking Test (CTT), a test developed in the 1960s to test pilots and astronauts for fatigue, illness, and stress, might help insure that only the most fit individuals are working on the flight deck that day.(5,6) How we manage the risks identified by these checklists and devices is another challenge. Strong leadership, adequate administrative procedures, and aggressive education and training are essential ingredients of any risk assessment and management program.

With regard to life stressors, dealing with these kinds of human factors has always been considered a "soft" and ill-defined area. However, life stressors keep coming up every time we consider probable causes of performance degradation that may have led to an aviation mishap. Weigmann and McKay found an inverse relationship between social support and physiological and psychological strain among flight deck personnel. (3) This suggests the more family, peer, and supervisory support an individual has, the less the perceived stress and the better the individual's performance. They identified a number of social support issues that if adequately addressed would potentially have a strong, positive effect on the morale of flight deck personnel and therefore on performance. Some of the issues identified were 1) timely contact with family members back home, 2) some personal autonomy in having a say in one's work schedule, 3) adequate work cloths and personal equipment throughout the carrier's deployment, 4) proper coordination of work groups into designated living quarters to insure adequate uninterrupted rest and some privacy, and 5) head of the line privileges to eat meals and to buy personal goods during the work day.

Educating and training leaders, supervisors, and workers to better understand the threats to optimal performance and how to best deal with them has always been a challenge. When to train, what to train, where to train, and how often to train not just our flight deck personnel but also our leaders and supervisors are continuous questions, and the answers need continuous revision. For example, the need to educate supervisors on the effects of social support on personnel performance and training them in risk assessment and management will necessitate modification of current training programs. Implementing these changes into current training programs will require an approach that has has a high probability of success. The U.S. Navy has adopted Dr. C. Edward Deming's Continuous Quality Improvement approach to general management, and calls its program "Total Quality Leadership." Given the military's unique missions, acceptance and implementation of this approach by Navy leaders has been and continues to be an enormous challenge.

Finally, applying current research findings to the carrier flight deck environment to enhance performance is a tremendous challenge, but should be an integral part of the continuous quality improvement process for flight deck operations. Several examples come to mind. One example is the use of "strategic napping." Shappell recently reported positively on the use of "strategic napping" in aircrew to enhance flight performance.(7) The question arises, "can this strategy be used for flight deck personnel and how should it be used to enhance their performance during long working hours?" Another example is the use of specific medications to enhance performance. In view of the U.S. Air Force's success in using stimulants and sedatives to enhance performance in their aircrew during Desert Shield/Desert Storm, the question arises, "could similar protocols be used successfully in flight deck personnel during sustained carrier flight operations?" Similarly, could melatonin be used to convert a "night owl" into a "morning type" person, and therefore enhance performance? With regard to the question of better screening tests for fitness, should psychological tests be developed and used to screen in only those individuals with the "right stuff" for flight deck work, e.g. "morningness." Finally, as alluded to earlier, should we use and how best can we use available fitness-for-duty devices, such as the FIT™ Test or the Critical Tracking Task Test to determine if flight deck personnel are able to perform their best on any particular day? These questions and many others, based on current research findings, should be addressed in our ongoing search to enhance neurological performance among aviation ground support personnel.

5. CONCLUSIONS

United States carrier flight deck personnel work in a unique aviation environment that is intense, prolonged, and very hazardous. These stresses may lead to a number neurologic problems which will limit performance. Better initial screening and periodic evaluation of personnel, daily risk assessment and management, improving education and training, addressing morale issues, and applying novel research findings, such as the use of performance enhancing drugs, are some of the practical challenges military leaders face in attempting to enhance neurologic performance among carrier flight deck personnel.

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14. Abstract

These proceedings include the Technical Evaluation Report, three Keynote Addresses, 33 solicited papers and four special session papers of the Symposium sponsored by the AGARD Aerospace Medical Panel and held at the Deutsche Forschungsanstalt für Luft- und Raumfahrt, Linder Höhe, Cologne, GE from 9-12 October 1995.

NATO air operations in the future will have improved capabilities for mobility, flexibility, rapid augmentation and situation awareness. The rapid changes and sophisticated innovations taking place in technology imply that air warfare will become more knowledge intensive and, accordingly, more dependent on a well conditioned nervous system. Advancements in technology are also driving air and the concomitant support operations into the outer limits of human mental and physical endurance. There is also the requirement of doing more work with fewer resources. The purpose of this Symposium was to address some of the factors that impose limitations on the nervous system, and to consider the practical challenges for enhancing neurological performance in such operational conditions as described above.

The papers addressed neurological limitations imposed by: (a) the Gz environment; (b) the hypoxia environment; (c) disease and trauma; (d) neurosensory limitations; (e) fatigue and sleepiness in workload; (f) stress effects; and (g) sustained operations. The practical challenges in enhancing neurological performance were addressed for: (a) heavy jet operations; (b) rotary wing operations; (c) air traffic control operations; and (d) ground and support operations.

These proceedings will be of interest to those concerned with the health and safety of personnel in air and support operations; and the aerospace scientist wanting a review of relevant research in the field of air operations neuroscience.

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